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INTERNATIONAL OMEGA NAVIGATION SYSTEM. WESTERN PACIFIC OMEGA VA--ETC(U)
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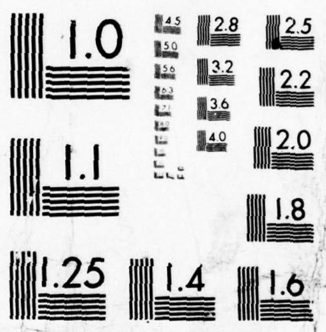


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL II

ONSOD 01-78

VOL-1

INTERNATIONAL OMEGA NAVIGATION SYSTEM

International Omega Navigation System.

WESTERN PACIFIC OMEGA VALIDATION

VOLUME I

TECHNICAL REPORT

F. G. Karkalik
G. F. Sage
W. R. Vincent

April 1978

132 p.

Prepared by

SYSTEMS CONTROL, INC. (Vt)
Palo Alto, California 94304

CONTRACT DOT-CG-71328A

for

OMEGA NAVIGATION SYSTEM OPERATIONS DETAIL
Washington, DC 20590

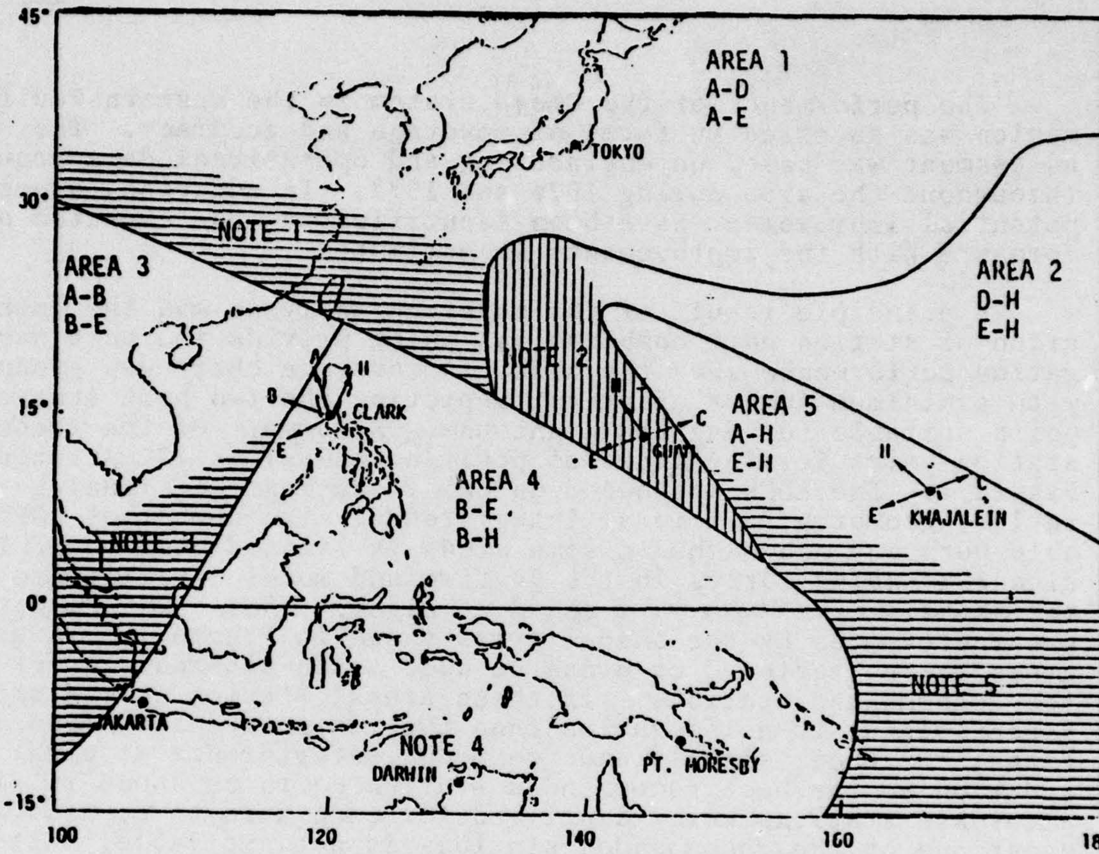
EXECUTIVE SUMMARY

The performance of the Omega system in the Western Pacific region was assessed in terms of coverage and accuracy. The assessment was based on engineering and operational data acquired throughout the area during 1976 and 1977. In addition, areas of potential improvement have been identified and the expected performance with the improvements is estimated.

A principle result of the coverage analysis was the determination of station pair combinations which provide the best navigation performance over the area. A coverage chart was produced, with a minimum number of areas, depicting the two best station pairs suitable for day and night use. A summary of the recommended station pairs forming lines of position (LOPs) is illustrated in Figure 1. The LOPs are based on considerations of signal-to-noise ratios, geometry, and modal interference. The number of LOPs available both day and night in some areas is limited because of low signal-to-noise ratios in the daytime and modal interference on the signals from Stations C and H at night. These two conditions are represented by the shaded areas shown in Figure 1. These are areas where Station C or H can be used as an alternative for one of the recommended stations. In these areas, Station C or H provide higher signal-to-noise ratios than the respective recommended stations, but their signals undergo modal interference at night. In addition to the best recommended station pairs as shown in Figure 1, alternate stations were identified for each area to be used in the event one of the recommended stations is not available. Alternate stations selected are described in Section VI of the report.

The alternate station analysis also provided an assessment of usable redundant signal coverage over the entire Western Pacific region. Redundant station coverage will be marginal in some areas until the Australian station is operational. At least one alternate station is available over 90% of the area during the night and 70% of the area during the day.

An accuracy assessment of the Omega system must consider two distinctly different, but related error sources. One is the position error which results from phase tracking noisy signals, taking into account geometry and propagation correction (PPC) induced errors, given that the correct cycle (Omega lane) is being tracked. The other error source is caused by tracking the wrong cycle (Omega lane). The lane error results from either initializing on the wrong lane or the Omega receiver slipping into the wrong lane while tracking. The lane widths, at 10.2 kHz, based on the recommended station pairs for the Western Pacific area,



Note 1: H can be used as an alternate for D during local daytime in shaded area.

Note 2: C can be used as an alternate for D during local daytime in shaded area.

Note 3: H can be used as an alternate for A during local daytime in shaded area.

Note 4: Alternate stations are not required in Area 4 when the recommended stations B, E, and H are available.

Note 5: C can be used as an alternate for A during local daytime.

Figure 1 Recommended LOPs for Western Pacific Area Coverage Based on Use of 10.2 kHz Only and Without Station G(Australia) Coverage

vary from 8 nmi to 25 nmi. The 25 nmi lane occurs when using LOP A-H east of Guam. Station C is recommended here as an alternate for A during local daytime, but not at night because of modal interference.

The position error resulting, given proper lane identification, obtains directly from statistical analysis of the monitor data. However, the position error resulting from tracking the wrong lane is not directly obtainable from the monitor data which is in terms of corrected phase measurements. The probability of lane error is highly dependent upon Omega receiver implementation and operation. Position accuracy was estimated for two generic receiver types: a manual single frequency LOP set and an automatic latitude/longitude three-frequency set. With a manual single frequency LOP receiver using strip chart recorders, proper lane identification is achieved by operator interpretation. Lane identification in automatic receivers is design dependent. In addition to the difference in lane identification, the accuracies of the two types of receivers, given correct lane identification, will differ because the automatic receiver can select stations based on current conditions.

The accuracy, given correct lane identification, was estimated for the two types of receivers. The measure of accuracy selected for the Omega position fix is the 95% circular error. The 95% circular error is the radius of a circle including 95% of the position fixes, both day and night. The stated accuracy goal of the Omega system is 1 nmi RMS during daytime and 2 nmi RMS at night. This can be translated to a day and night 95% circular error of 4 nmi.

For the automatic Omega receiver, the estimated 95% circular error, based on the data at the sites shown in Table 1, is 6.3 nmi. For the manual receiver, using the LOPs shown in Table 1, the estimated 95% circular error is 7.3 nmi. Substantial improvements in accuracy can be achieved by propagation correction (PPC) improvements as has already been accomplished in other geographical regions. To illustrate the potential improvement, a random sample based on 24 hourly measurements taken from the Clark BE-EH, July 1976, data was analyzed. The 95% circular position error centered about the true position was 10.3 nmi. After PPC improvements, the expected performance should approach a 95% circular error of 3.5 nmi for the user with an automatic receiver and 4.3 nmi for the user with a manual receiver. These accuracies are compatible with the stated Omega accuracy goal.

Since a determination of the probability of identifying the correct lane could not be made directly from the data, an estimate of correct laning by the use of the 3.4 kHz difference frequency was made based on an analysis of 10.2 kHz and 13.6 kHz data.

Table 1

Accuracy Summary

95% Circular Error

SITE	AUTOMATIC SYSTEM		MANUAL RECEIVER		
	PRESENT PPCs nm	IMPROVED PPCs nm	LOP PAIR	PRESENT PPCs nm	IMPROVED PPCs nm
Kwajalein	4.4	2.5	AH EH	8.4	7.5
Orote Pt	5.4	2.1	DH EH CH EH	5.4	2.1
Clark	7.1	3.7	BE EH	8.6	4.0
Tsushima	6.7	3.0	AD DE	6.7	3.6
Darwin	6.8*	3.7*	BE EH	8.3*	4.1*
Overall	6.3	3.4		7.3	4.3

* Estimated

The result of this analysis shows that using the present PPCs, laning errors can be expected to occur between 14% and 23% of the time. When the PPC improvements are made, the laning errors should be reduced to between 2.8% and 3.9% of the time.

Specific conclusions are:

- Coverage Assessment

  The Omega system coverage over the Western Pacific area can support enroute air and marine navigation. Care is required to select the best station combinations depending on location within the area and time of day. A recommended set of combinations is shown in Figure 1. In the event one or more of the recommended stations is off the air, alternate stations have been identified. The selection criteria will be considerably simplified by the addition of Station G in Australia. Station G should provide usable signals over the entire area at all times.

- LOP Phase Accuracy

  Analysis of the phase difference data from the monitor sites indicate LOP accuracies with hourly mean averages of about 15 CEC. Standard deviations about the means of less than 10 CEC are generally observed. The hourly mean errors can be substantially reduced by improving PPCs, resulting in a significant improvement in position accuracy and laning reliability. When the Australia station, G, becomes operational, LOP errors (both means and standard deviations) will be improved since strong stable signals from G can be paired with other signals in the area to provide more reliable LOPs.

- Position Fix Accuracy

  Omega position fix accuracies were determined by combining available LOP pairs. The 95% circular error ranged from 4.4 nmi to 7.1 nmi for automatic receivers and 5.4 nmi to 8.6 nmi for manual receivers using the present PPCs. PPC improvement can significantly reduce these errors since the hourly mean errors are generally larger than the variations about them. Position fix accuracies will be further enhanced by the advent of the Australian station, G, since the azimuth of the arriving signals from G in the Western Pacific provide improved geometric LOP combinations when combined with signals now available.

- Loran-A Replacement

  In the areas that were serviced by Loran-A 1H1, 1H2, 2L1, 2L2, 2L3, and 2H6 chains which were discontinued on 31 December 1977, current Omega coverage from at least three stations is available. Over the Mariana Island region, redundant coverage is marginal during times when either Station E or H is off the air. Station G, Australia, will provide the needed redundancy over this region.

- Charted LOPs

  Recommended LOP pairs should be noted on Omega charts in those regions where they provide the best service. Alternate LOPs should also be noted, with an indication of the performance to be expected.

- Signal-to-Noise Ratios

  The Omega data analyzed generally support the coverage predictions. In those cases where minor differences were found, the predictions based on the Effective Single Mode Model are usually more conservative than the data indicate. The significant differences that exist, observed during NOSC temporary site measurements, are: signal strength from Station B is 8 to 18 db higher than predicted at Clark, Orote Point, Port Moresby and Darwin, and signal strength from Station C is 4 to 10 db lower than predicted at Port Moresby and Darwin.

- Modal Interference

  Modal interference is predicted from Station H, Japan, during nighttime within the sector between the 190° and 225° bearing angles from the station. Flight tests conducted on bearings of 205° and 215° from the station validated the predictions and showed the deepest nulls at approximately 3 and 4 Mm (1620 and 2160 nmi) from the station. Modal interference is predicted from Station C, Hawaii, during nighttime within the sector between the 190° and 295° bearing angles from the station. Amplitude data from nighttime test flights between Hawaii and Wake Island on approximately a 270° bearing from Hawaii, confirmed the existence of modal interference. However, the test data amplitude signatures from the two flights did not correlate well with each other or with the predictions indicating significant night-to-night variations in the modal structure. Navigation based on a single frequency exhibiting severe modal interference is susceptible to lane slippage. However, modal nulls at different frequencies are spatially displaced which suggests the use of two or more frequencies as a means to reduce the incidence of modally induced lane slippage.

- Multifrequency Operation

  Use of multiple frequencies gives a significant increase in the availability of position fixing over the use of 10.2 kHz only. The 13.6 kHz signal provides a better received S/N than does 10.2 kHz. Based on the data analyzed, the 3.4 kHz difference frequency does not appear to provide sufficient accuracy for reliable laning with the present PPCs. A realizable improvement in the PPCs should provide adequate laning performance.

ACKNOWLEDGEMENTS

The information and data reviewed and analyzed during the preparation of this report was made available through the efforts of several organizations and individuals. In addition to the scientific and engineering data provided by the Naval Ocean Systems Center (NOSC) and ONSOD, valuable operational data were provided by the U.S. Navy, U.S. Coast Guard, Magnavox, and Pan American World Airways.

Special mention must be made of the helpful review and discussion of results by E.R. Swanson and J.E. Bickel of NOSC and P.B. Morris and D. Scull of ONSOD. Also the authors wish to recognize the valuable support provided by ONSOD and SCI computer programming staffs.

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I. INTRODUCTION

The United States Coast Guard Omega Navigation System Operations Detail (ONSOD) is currently examining Omega Navigation System performance in the Western Pacific area to ascertain if Omega provides a viable sea and air navigation service for the area. Emphasis was placed on the need to examine and validate Omega performance by the shutdown of U.S.-operated Loran-A stations in the Western Pacific on December 31, 1977. The growing number of Omega users in the Western Pacific and the need for an alternate long-range navigation capability to replace Loran-A in the area require the verification of Omega usability in this area.

For the past few years ONSOD has operated fixed Omega monitoring sites in the Western Pacific to collect long-term performance data at selected locations. Additional technical support has been provided to ONSOD by the Naval Ocean Systems Center (NOSC), San Diego, California, who has collected Omega data from aircraft flights and temporary fixed sites. Preliminary users of Omega have contributed practical operational experiences and observations throughout the area of interest. These sources have provided a comprehensive data base from which considerable information on Omega performance and accuracy estimates have been obtained.

Systems Control, Inc. was placed under contract to ONSOD to aid in evaluating the current performance of Omega in the Western Pacific area. This effort included the assembly of available data, the processing and conversion of available data into formats useful for evaluation purposes, and the analysis and interpretation of the various forms of data. Additional results from NOSC data will be available in NOSC reports. Hourly averages of line of position (LOP) phase measurements data taken over several months at seven ONSOD fixed monitor sites located within the Western Pacific area

were reviewed. This data was supplemented with data taken over the area by a dedicated flight test conducted by NOSC. In addition, operational Omega navigation observations provided by ship and aircraft crews were evaluated.

Statistical analyses were performed on the data, the results of which were compared to predictions wherever possible. Summaries of the analysis results were reviewed, interpreted and structured in the form of tables and charts in order to present Omega performance guidelines with a reasonable degree of traceability to the basic measured data.

The performance data from monitor sites and operational users were reviewed to identify areas where improvements in system performance could be expected. The areas of potential improvement are identified and recommendations are made for implementation in the Omega system.

Data presented in this report were based on the current configurations of Omega stations which did not include the Australia station. The Australia station is expected to become operational in 1980, and it will provide excellent coverage of the Western Pacific area in terms of signal-to-noise ratio and geometry. Signals from Australia will substantially improve the general Omega performance capability in the Western Pacific area.

Volume I discusses the background, method of approach, data available for analysis and presents summary data analysis results along with the conclusions and recommendations. Volume II contains summary graphical displays of the analyzed ONSOD monitor site LOP data from Kwajalein, Orote Point, Clark AB, and Tsushima.

II. BACKGROUND AND OBJECTIVES

Omega is a very low frequency (VLF) radio navigation system operating in the internationally allocated frequency band between 10 and 14 kHz. It is capable of providing all-weather navigation service throughout the world with only eight transmitting stations. Locations of the stations are listed in Table 2.1. The system is usable for navigation purposes by ships, aircraft, and land vehicles. The Omega system is on the threshold of being declared fully operational.[1] As such, the system will serve as a replacement for older radio navigation systems such as Loran-A.[2] The Department of Defense has stated that the U.S. military requirement for Loran-A terminated on 31 December 1977. The U.S. Coast Guard terminated operation and support of its overseas Loran-A stations in the Western Pacific on 31 December 1977, and is scheduled to discontinue operation of the domestic Loran-A stations over the period 1 July 1979 through 1 July 1980.[3] The Department of Defense has further stated that Omega has been selected as the replacement for Loran-A to meet military requirements. The U.S. Coast Guard's Omega Navigation System Operations Detail (ONSOD) is responsible for determining or validating, within its resources, the overall worldwide capability of Omega.[4]

The validation of Omega usability in the Western Pacific is the first project on ONSOD's long-range Regional Validation Program. This program is structured so as to substantiate Omega capability in several oceanic regions in view of the shutdown of Loran-A transmitting stations in those regions. In succeeding years, validation efforts will address other areas of the world.[5]

Table 2.1

Omega Transmitting Station Network

STATION LETTER DESIGNATION	SITE	APPROXIMATE LATITUDE/LONGITUDE	COGNIZANT AGENCY
A	ALDRA, NORWAY	66°25'N/13°08'E	Norwegian Telecommunications Administration
B[1]	MONROVIA, LIBERIA	6°18'N/10°40'W	Liberian Dept. of Commerce, Industry and Transportation
C	HAIKU, HAWAII	21°24'N/157°50'W	U.S. Coast Guard
D	LA MOURE, N.D.	46°22'N/98°20'W	U.S. Coast Guard
E	LA REUNION	20°58'S/55°17'E	French Navy
F	GOLFO NUEVO, ARGENTINA	43°03'S/65°11'W	Argentine Navy
G[2]	AUSTRALIA	38°29'S/146°56'E	Australian Dept. of Transportation
H	TSUSHIMA, JAPAN	34°37'N/129°27'E	Japanese Maritime Safety Agency

1 Station B, Liberia, is operated by a U.S. Contractor sponsored by the U.S. Government.

2 A temporary station at Trinidad (10°42'N/61°38'W) operated by the U.S. Coast Guard is transmitting in the G time slot. The Trinidad station will cease operation on 31 March 1978. The station in Australia is expected to become operational in 1980.

III. METHOD OF APPROACH

System validation for a given region is, in general, a process of confirming or modifying (if necessary) propagation and error models which have been used to ascertain "coverage" indices and accuracy figures for that region. To verify and/or test these models, various types of data are required, such as signal field strength and phase at a fixed location versus time, noise level, signal-to-noise (S/N) ratio, single-station phase and amplitude versus distance, diurnal phase, phase difference, and position fix measurements.

After measurements are made and the prediction models are confimed or modified, the remaining effort consists of documenting, or defining, Omega usability in a particular region. In this context, "defining Omega usability" means specifying which transmitting station signals are accessible to a given area at a particular time and the position accuracy provided by these signals.

The specific steps of the validation process are listed below.

(1) Select Area: The Western Pacific region is subdivided into several smaller areas having common characteristics, such as geometry or signal coverage. For purposes of this report, the regions in the proximity of specific monitor sites are chosen as they represent bases for display of experimental data.

(2) Review Predicted Coverage Contours: One purpose of the Omega validation is to assess the accuracy of analytical predictions characteristic of the system. The primary predictions relate to signal coverage which is generally described by coverage contours.[5] These contours are superimposed on the subregions for subsequent validation.

(3) Select Station Data for Analysis: Based on the coverage contours, the specific stations providing coverage in the subregions are selected for analysis.

(4) Analyze S/N Data: The S/N data obtained for those stations predicted to provide adequate signals are analyzed and compared to the predictions. Where significant differences arise, these are noted for potential modifications to the predicted coverage contours.

(5) Modal Interference Data: Analytical predictions indicate potential modal interference over certain regions at night. Several of the tests are dedicated to examine this problem. Using the test data with other data gathered from the monitor sites, modal interference will be analyzed and compared to predictions.

(6) Modify Coverage Contours: Modifications to the coverage contours are performed based on the S/N data and modal interference data. The resultant contours will be representative of actual coverage conditions.

(7) Select Line of Position (LOP) Combinations: Having established those Omega stations providing coverage, the next step in the validation procedure is to examine achievable accuracies. The initial step in the accuracy analysis is choosing station pairs which provide the most favorable LOPs for position fixing.

(8) Analyze Phase and Phase Difference Data: Achievable Omega accuracies are dependent on the accuracy of the Propagation Corrections (PPCs). Validation of PPC accuracy is achieved by comparing observed Omega phase and phase difference data. These data are analyzed to validate the PPCs.

(9) Analyze Position Accuracy Data: LOP pairs are selected based on the previous analyses and LOP crossing angles. Using the LOP errors ascertained from the phase/phase difference data, an estimate is made of the expected Omega position fix accuracy for each LOP pair combination selected.

(10) Compare with Operational Data: Generally, the data analyzed thus far represents data gathered under test conditions. It is desirable to calibrate the

test data by a comparison with data gathered under normal operational conditions. This step in the validation process compares the results obtained with operational data.

(11) Identify Optimum Stations for Area: Based on S/N and achievable position fix accuracy, the stations providing optimum Omega system utilization for the region of interest are identified.

(12) Identify Alternate Stations for Area: Where applicable, additional stations are identified that can be used for Omega navigation in a fail-soft mode. Typically, these stations do not provide optimum position fix geometry, but do provide adequate position fix capability in the event that a primary station cannot be used.

(13) Identify Worst Case Situation: For specific times, such as noon, midsummer, regions of marginal coverage may exist. Also the LOP geometry for a given set of stations that can be received may be suboptimal. These areas are identified and the significance of any impacts on navigation noted.

(14) Identify Areas of Improvement: If the system performance reported by a monitor or user does not meet system goals, the reason is identified. A method of improving performance is recommended to meet system goals.

IV. DATA AVAILABLE FOR EVALUATION

Data were available from a number of sources for the examination of Omega Navigation System performance in the Western Pacific area. These sources included Omega signals monitored at fixed sites, during special aircraft flights, by commercial aircraft, by merchant ships, by USCG ships, and by U.S. Navy ships. While the type of data and the format of the data varied from source to source, data from each source were found to be useful in the evaluation of Omega performance. Data from each source are described in the following subsections.

4.1 ONSOD FIXED-SITE MONITOR DATA

ONSOD has deployed Omega receivers in a worldwide monitoring network to provide measured data on the quality and accuracy of Omega signals.[5] Seven of these monitor sites were located in the Western Pacific region. Of these seven, considerable data were available from four sites (Kwajalein, Orote Point, Clark AB, and Tsushima) and small amounts of recently collected data were available from three sites (Darwin, Port Moresby, and Miyako Jima). The data base available for this study from the ONSOD fixed sites is summarized in Table 4.1. This table indicates the data frequencies and stations providing data. These data were primarily in the form of measurements of phase difference between pairs of received signals. The phase difference data were used to calculate Omega position fix values for each site for an analysis of Omega position accuracy.

4.2 NAVAL OCEAN SYSTEMS CENTER DATA

The Naval Ocean Systems Center (NOSC) of San Diego, California, was tasked with a significant field measurement and data analysis

Table 4.1
ONSOD Monitor Station Data

● KWAJALEIN, MARSHALL ISLANDS, FILE 1

	FREQUENCY		LOP									
DATE	10.2	13.6	AC	CH	DH	CD	AE	AH	EH	AB	BH	CE
10/75	✓		✓									
11/75	✓		✓	✓	✓	✓						
12/75	✓		✓	✓	✓							
1/76	✓		✓	✓	✓							
2/76	✓		✓	✓	✓							
3/76	✓	✓	✓	✓	✓							
4/76		✓	✓	✓	✓							
7/76	✓	✓					✓	✓	✓			
8/76	✓						✓	✓	✓			
9/77	✓						✓		✓	✓	✓	✓

● KWAJALEIN, MARSHALL ISLANDS, FILE 2

	FREQUENCY		LOP								
DATE	10.2	13.6	AD	AH	DE	EH	AC	AE	CE	CH	DH
12/76	✓		✓	✓	✓	✓					
1/77	✓		✓	✓	✓	✓					
2/77	✓		✓	✓	✓	✓					
3/77	✓		✓	✓	✓	✓					
4/77	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
5/77	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
6/77	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
7/77	✓					✓	✓	✓	✓	✓	✓
8/77	✓					✓	✓	✓	✓	✓	✓
9/77	✓					✓	✓	✓	✓	✓	✓
10/77	✓					✓	✓	✓	✓	✓	✓

Table 4.1 (Continued)
ONSOD Monitor Station Data

● OROTE PT., GUAM

	FREQUENCY		LOP						
DATE	10.2	13.6	AC	CH	DH	CD	AE	AH	EH
10/75	✓		✓						
11/75	✓		✓	✓	✓	✓			
12/75	✓		✓	✓	✓				
1/76	✓		✓	✓	✓				
2/76	✓		✓	✓	✓				
3/76	✓	✓	✓	✓	✓				
4/76		✓	✓	✓	✓				
7/76	✓	✓					✓	✓	✓
8/76	✓						✓	✓	✓

● CLARK AB, PHILIPPINES

	FREQUENCY		LOP				
DATE	10.2	13.6	AC	CH	AB	BE	EH
1/76	✓	✓	✓	✓			
2/76	✓	✓		✓			
4/76	✓	✓	✓	✓			
5/76	✓	✓			✓		
6/76		✓			✓		
7/76	✓	✓			✓	✓	✓
8/76	✓						✓
12/76	✓		✓	✓	✓		
1/77	✓		✓	✓	✓		
2/77	✓		✓	✓	✓		
3/77	✓		✓	✓	✓		
4/77	✓			✓			
5/77	✓		✓	✓	✓		

Table 4.1 (Continued)
ONSOD Monitor Station Data

● TSUSHIMA, JAPAN	FREQUENCY		LOP			
DATE	10.2	13.6	AH	CH	DH	EH
4/75	✓	✓	✓	✓	✓	
5/75	✓	✓	✓	✓	✓	
6/75	✓	✓	✓	✓	✓	
7/75	✓	✓	✓	✓	✓	
8/75	✓	✓	✓	✓	✓	
9/75	✓	✓	✓	✓	✓	
10/75	✓	✓	✓	✓	✓	
11/75	✓	✓	✓	✓	✓	
12/75	✓		✓	✓	✓	
1/76	✓		✓	✓	✓	
2/76	✓		✓	✓	✓	
3/76	✓	✓	✓	10.2	10.2	
4/76	✓	✓	✓	✓	✓	
5/76	✓	✓	✓	✓	✓	
6/76	✓	✓	✓	✓	✓	
7/76	✓	✓	✓	✓	✓	✓
8/76	✓	✓	✓	✓	✓	✓

Table 4.1 (Concluded)

ONSOD Monitor Station Data

● DARWIN, AUSTRALIA

	FREQUENCY	LOP					
DATE	10.2	AB	AE	BH	CE	CH	EH
8/77	✓	✓	✓	✓	✓	✓	✓
9/77	✓	✓	✓	✓	✓	✓	✓
10/77	✓	✓	✓	✓	✓	✓	✓

● PORT MORESBY, NEW GUINEA

	FREQUENCY	LOP		
DATE	10.2	CE	CH	EH
8/77	✓	✓	✓	✓
9/77	✓	✓	✓	✓
10/77	✓	✓	✓	✓

● MIYAKO JIMA, JAPAN

	FREQUENCY	LOP		
DATE	10.2	AH	CH	EH
6/76	✓	✓	✓	✓
7/76	✓	✓	✓	✓
8/76	✓	✓	✓	✓
9/76	✓	✓	✓	✓
10/76	✓	✓	✓	✓
4/77	✓	✓	✓	✓

effort for the validation of Omega performance in the Western Pacific Ocean area. This effort included aircraft and temporary fixed-site measurements of Omega signals, the comparison of received signals with predictions and the analysis of results.

NOSC, in cooperation with the USAF, instrumented a USAF KC135 aircraft with Omega receiving equipment. The aircraft was flown along the routes shown in Figure 4.1 in a sequence of flights from 10 August 1977 to 13 October 1977.[7] Omega signal amplitude and phase data were collected on all flights from Omega stations providing coverage for each route. In addition, a standard Omega navigation receiver was used to obtain navigation data which were compared with navigation data from the aircraft INS. Other VLF receivers monitored VLF communications signals for auxiliary data. The measurements from NOSC aircraft flights in the Western Pacific are summarized in Table 4.2.[7] The flight numbers in this table correspond to those shown on the chart of Figure 4.1.

In addition to aircraft measurements, NOSC personnel established temporary fixed Omega monitoring stations at Wahiawa, Hawaii; Kwajalein; Orote Point, Guam; Clark Ab, Philippines; Darwin, Australia; Jakarta, Indonesia. These sites operated at times ranging from one to more than three months during the period of July 1977 through October 1977. Table 4.3 provides a summary of data available from the NOSC temporary monitoring sites.

The NOSC aircraft flight paths and temporary fixed-site locations provide excellent short-term coverage of the Western Pacific area to supplement longer term data obtained from ONSOD sites described in the previous section. Signal amplitude data was made available from measurements at Clark, Orote Point, Port Moresby, and Darwin and from the Station H modal interference flight tests. NOSC will be reporting on the results of their analysis of the additional data.

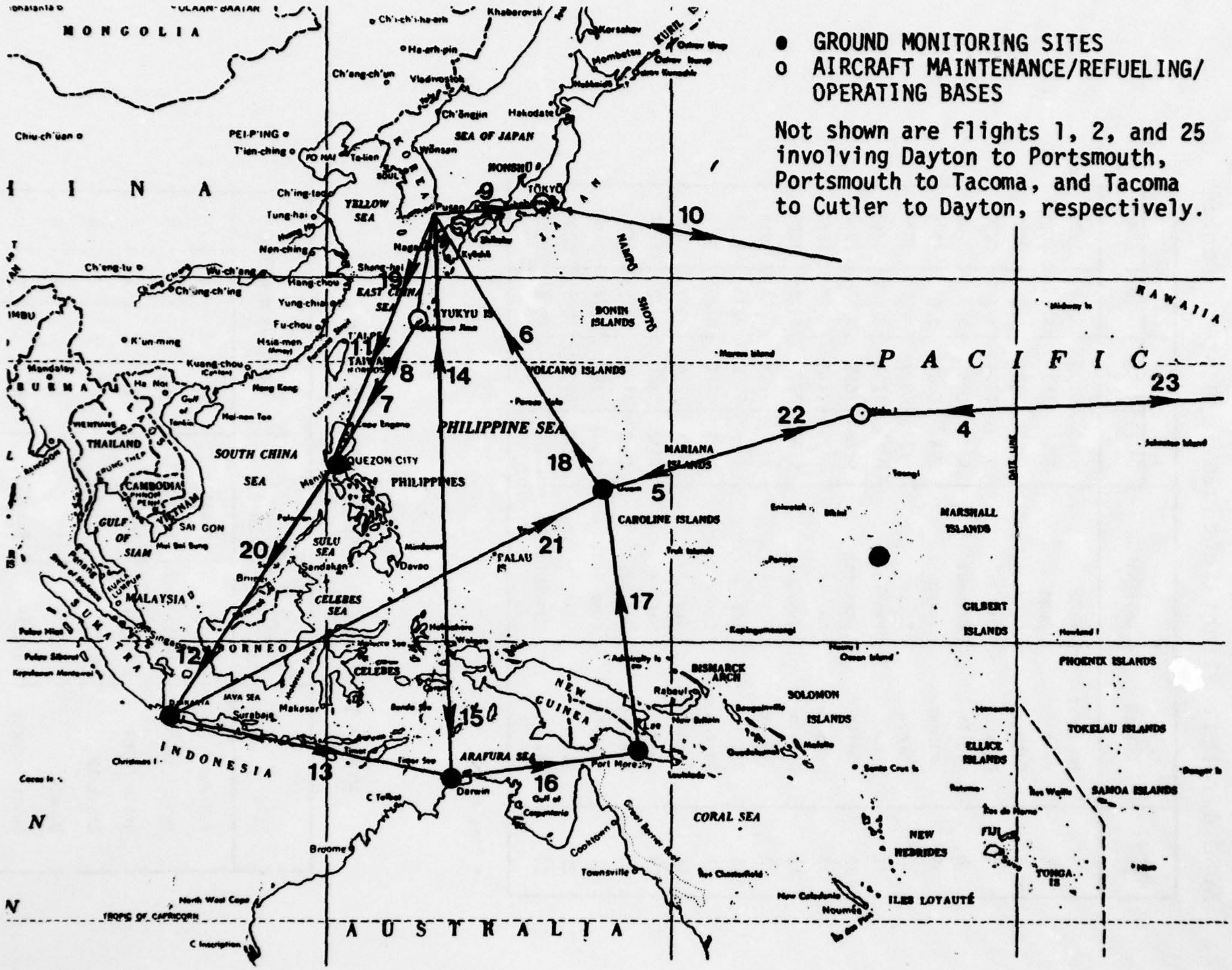

Figure 4.1 Aircraft Flight Itinerary/Ground Monitoring Sites[7]

Table 4.2

NOSC Aircraft Flight Schedule in Western Pacific[7]

FLIGHT NO.	ORIGIN	DESTINATION	LV		AR	
			DATE	TIME*	DATE	TIME*
4	Honolulu	Wake	8/18	0500	8/18	1024
5	Wake	Guam	8/18	1159	8/18	1525
6	Guam	Okinawa	9/1	2302	9/2	0453
7	Okinawa	Manila	9/3	0700	9/3	0930
8	Manila	Okinawa	9/5	0035	9/5	0246
9	Okinawa	Tokyo	9/6	0801	9/6	1055
10	Tokyo	Tokyo	9/17	0900	9/17	1525
11	Tokyo	Manila	9/18	1233	9/18	1743
12	Manila	Jakarta	9/22	1635	9/22	2214
13	Jakarta	Darwin	9/24	1418	9/24	1805
14	Darwin	Iwakuni	9/26	1201	9/26	1925
15	Iwakuni	Darwin	9/27	1155	9/27	1916
16	Darwin	Port Moresby	9/28	1256	9/28	1555
17	Port Moresby	Guam	9/30	1117	9/30	1517
18	Guam	Iwakuni	10/1	1214	10/1	1640
19	Iwakuni	Manila	10/2	1301	10/2	1717
20	Manila	Jakarta	10/2	1846	10/2	2320
21	Jakarta	Guam	10/4	1151	10/4	1805
22	Guam	Wake	10/6	0529	10/6	0855
23	Wake	Honolulu	10/6	1009	10/6	1505

* Time in GMT

Table 4.3

NOSC Temporary Monitoring Sites[7]

SITE	START DATE	END DATE	STATIONS MONITORED			
Wahiawa	7/13/77	7/31/77	A	D	E	H
Kwajalein	10/11/77	10/31/77	B	C	E	H
Orote Point	7/21/77	10/31/77	B	C	E	H
Clark AB	7/26/77	10/31/77	A	B	E	H
Darwin	8/2/77	10/31/77	B	C	E	H
Point Moresby	8/9/77	10/31/77	B	C	E	H
Jakarta	9/25/77	10/31/77	B	C	E	H

4.3 OPERATIONAL DATA

Several initial users of Omega navigation have conducted operational evaluations in the Western Pacific region. Typically, position fix and signal reception data are recorded. Operational data have been contributed by the following sources:

- Pan American World Airways[8]

Date	Itinerary	Stations Used As Available
6/29/77	Honolulu, Guam, Manila	ABCDEH
7/10/77	Manila, Guam, Honolulu	ACDEH
7/17/77	Honolulu, Tokyo	BCDEH
7/18/77	Tokyo, San Francisco	BCDEH
9/17/77 - 9/27/77	Honolulu, Nandi, Adelaide, Singapore, Kuala Lumpur, Naha, Oita, Tokyo, San Francisco	ABCDEFGH
11/8/77 - 11/11/77	Tokyo, Guam, Okinawa, Naha, Tapei, Guam, Singapore, Guam	ABCDEH

- U.S. Navy Ships

  USS Monticello transit from Subic Bay, R.P. to Pattaya Beach, Thailand via Sattahip from 2/15/77 to 2/19/77.[9]

- U.S. Coast Guard Ships

  USCGC JARVIS operations in North Pacific using LOPs AC, CD, DE and CH in early 1976.[10]

  USCGC MALLOW recorded Omega and Loran-A operational data in transit from Honolulu to the Marshall Islands in April 1977.[11]

- Merchant Ships

  The Chevron SS Burnaby transitted from Canaport to Ras Tanura, Saudi Arabia via the Cape of Good Hope, thence to the U.S. West Coast lightering area off Southern California via Lombok Strait, then back to Ras Tanura. Five Omega receivers were evaluated during the period August 1976 to December 1976.[12]

The Pacific Far East Lines SS Monterey transitted from Los Angeles to Hawaii, throughout the Western Pacific and returned to Los Angeles during the period 29 September 1977 to 19 November 1977. Position fix and S/N data were collected using a Magnavox MX1102/4 transit navigator/Omega monitor. Processed data for points where both satellite and Omega fixes were achieved were provided by the Magnavox Company for review.[13]

The States Steamship Lines SS Wyoming transitted from Los Angeles to Okinawa, throughout the Western Pacific and returned to Los Angeles during the period 30 September 1977 to 24 November 1977. Position fix and S/N data were collected using a Magnavox MX1102/4 transit navigator/Omega monitor. Processed data for points where both satellite and Omega fixes were achieved were provided by the Magnavox Company for review.[13]

4.4 LORAN-A DATA

The need for Loran-A data was for the purpose of comparing performance of Loran-A to Omega over those Loran-A service areas discontinued on 31 December 1977. Since no recent Loran-A test data were available, coverage charts and operational data were used for the comparison. Data available for analysis consisted of the following:

- Report of Loran-A System Performance Test; calibration data for Loran-A chains in operation in Western Pacific region.[14]
- Published coverage maps.
- Continental Airlines operational data for 19 flights between Honolulu and Guam.[15]
- USCG Cutter Mallow operational data collected during maneuvers in vicinity of Kwajalein.[11]

V. OMEGA PERFORMANCE EVALUATION

5.1 GENERAL APPROACH

The data base available for the evaluation of Omega performance in the Western Pacific area is described in Section IV. These data were subjected to critical examination and analysis. Data from each source were evaluated separately and then collated with data from other sources to ensure that all possible factors of importance were examined. Two questions were constantly considered during the evaluation process. These questions were:

(1) Does Omega currently provide a reasonable sea and air navigation service in the Western Pacific?

(2) Did any significant negative factor or wide deviation from expected performance appear in the data?

Subsequent sub-sections examine and analyze data received from each source. The analysis process started with a review of the best available predictions of Omega signal usability (Section (5.2) These predictions were compared with measured results and the operational experience of Omega users. Data from the ONSOD fixed Omega monitoring sites in the Western Pacific area were processed and plotted (Section 5.3). The ONSOD fixed-site data provided the major source of information for the Omega validation effort. Recently collected NOSC aircraft and temporary fixed-site data are described and examined in Section 5.4. Operational data provided by initial users of Omega in the Western Pacific are discussed in Section 5.5.

Traditionally, Omega accuracy and operating characteristics have been quoted separately for both day and night periods. However, it is undesirable to have the navigator constrained by performance available only at a specific time. This consideration guides the analysis to include both day and night data in the statistical summaries.

5.2 PREDICTED OMEGA SIGNAL USABILITY CONTOURS

Contour maps showing the predicted coverage of each Omega station in the Western Pacific were prepared. A map representing mid-day, midsummer coverage is shown in Figure 5.1, and a map representing midnight, midwinter is shown in Figure 5.2. The contours represent a S/N of -20 db in a 100 Hz receiver bandwidth except where modified to account for regions of severe modal interference. Each -20 db contour is labeled with a station designation and an arrow in the direction of the usable signal. The predicted contours are based on the Wave Guide Mode Full Wave Model, WKB (Wentzel, Kramers, and Brillouin), of VLF propagation.[6]

The predictions shown in Figures 5.1 and 5.2 represent expected extremes in coverage over a year's period. The predicted contours provide a convenient reference for comparison with both measured and operational results. It is important to keep in mind that these predictions are based on local summer noon and local winter midnight propagation conditions, respectively. In addition to validating the prediction with data wherever possible, part of the validation effort was directed towards assessing which stations are usable at intermediate times.

The location of fixed Omega monitoring stations of ONSOD and the temporary fixed sites of NOSC are also shown in Figure 5.1 and 5.2. The ONSOD site locations are identified by arrows pointing toward the Omega stations of primary interest for each site.

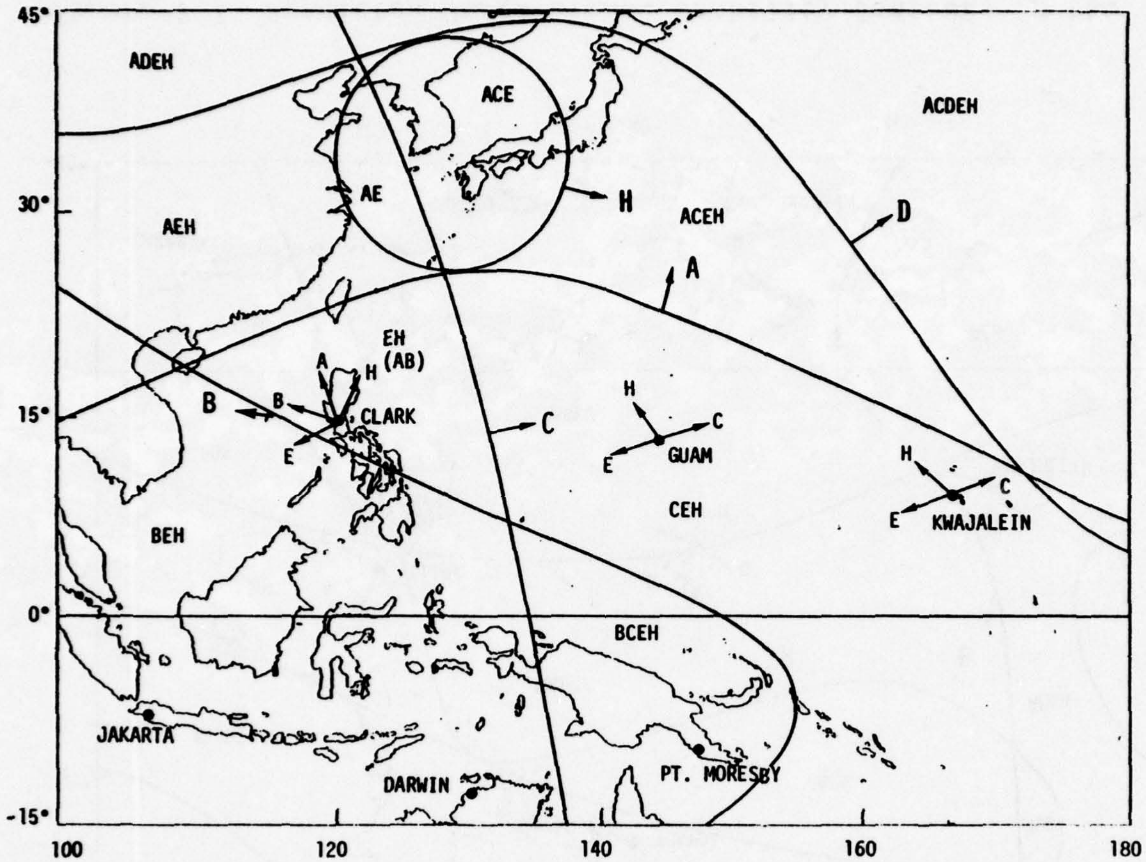

Figure 5.1 Predicted Omega Signal Usability Contours in the Western Pacific, Local Summer Noon, F = 10.2 kHz

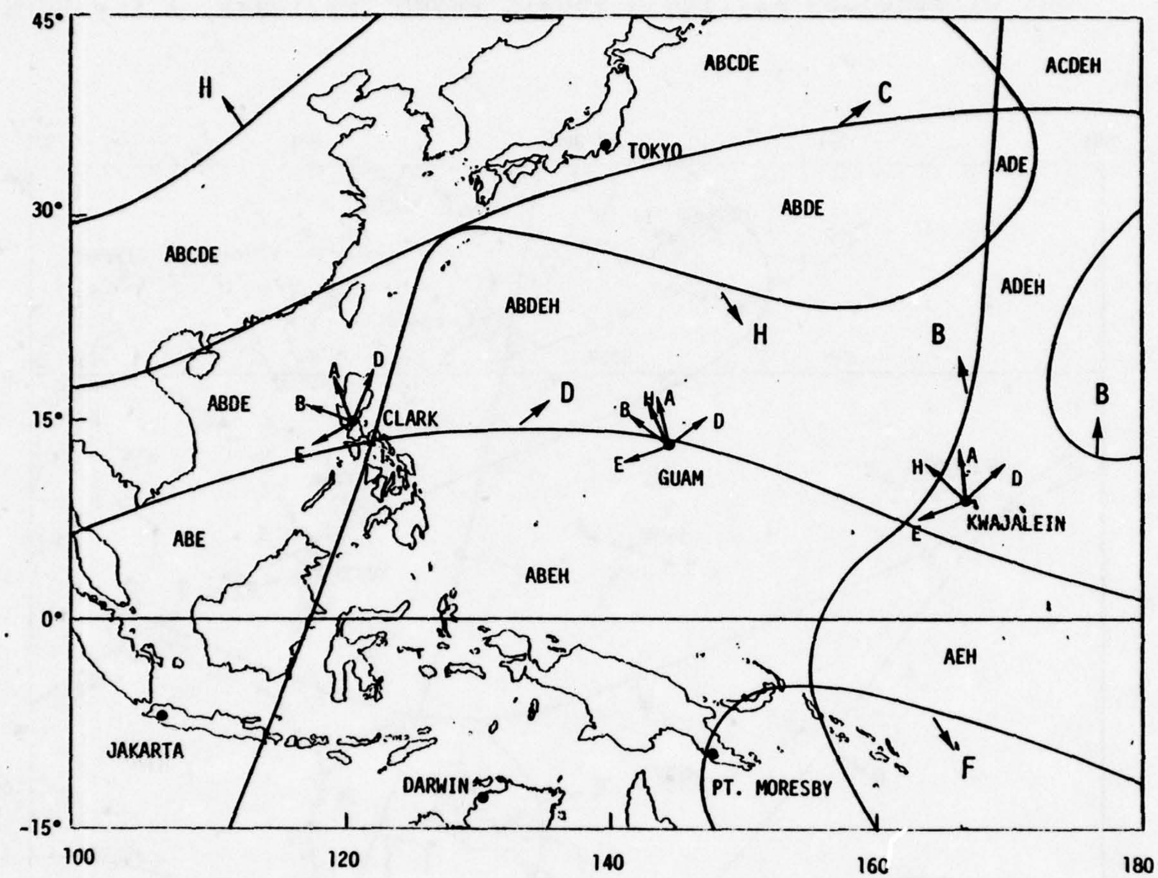

Figure 5.2 Predicted Omega Signal Usability Contours in the Western Pacific, Local Winter Midnight, F = 10.2 kHz

5.3 ONSOD FIXED SITE MEASUREMENTS

5.3.1 General Considerations

Omega data accumulated by ONSOD monitoring sites located in the Western Pacific area provided a highly useful and valuable data base from which measured performance and accuracy statistics were obtained. Data from these sites (see Table 4.1) were provided by ONSOD in the form of digital magnetic tapes. These tapes were computer processed to extract pertinent data and place these data in formats suitable for analysis. Processed data from the four ONSOD sites with long-term measurements are located in a series of appendices as follows:

Appendix A - Kwajalein Data
Appendix B - Orote Point Data
Appendix C - Clark AB Data
Appendix D - Tsushima Data

Representative examples of data from each appendix are shown in subsequent subsections along with a discussion of all ONSOD fixed site data which were analyzed. Lesser amounts of data were obtained from three sites (Darwin, Port Moresby, and Miyako Jima). These data are presented in subsections which follow the Kwajalein, Orote Point, Clark AB and Tsushima analyses.

Since more data were available from the ONSOD Omega monitoring sites than could be processed under the current effort, and some data were unsatisfactory for processing (for a variety of reasons defined later), the available data were carefully examined to ascertain which portions were most suitable for analysis. A data selection criterion was established to select the LOPs and LOP pairs considered to be most suitable for analysis. Factors considered in the selection process were (1) masterfile data availablity, (2) LOP geometry, and (3) predicted S/N.

A review of the ONSOD masterfile indicated that significant blocks of data were flagged with warning indicators. These indicators were as follows:

Indicator	Definition
S	Sudden ionospheric disturbance
P	Polar cap absorption
U	Unknown anomaly
T	Transmitter out
M	Monitor out
L	Insufficient data for statistical analysis
Q	Data is beyond acceptable value

L and Q flags require careful definition. The average and standard deviation for phase readings taken at a given hour for the month are computed. Any data beyond the larger of two standard deviations, or 8 centicycles from the average, are flagged Q and called outliers. The statistics are recomputed and another search for outliers is made. The process is completed when no additional outliers are found or if less than 10 unflagged data points remain. If less than 10 unflagged data points remain or the phase error standard deviation is greater than 15.0 all data points not yet flagged are flagged L.

If at least 50% of the data for a given month were unflagged, then data for that month were considered acceptable for analysis. If less than 50% of the data were unflagged and data flagged as S, P and U only raised the usable monthly data to at least 50%, then the month was considered acceptable for processing. Months which contained the S, P and U indicators and which were used for subsequent analysis were noted for later examination.

Table 5.1 lists months which passed the above flagged data criteria. The table lists the percentage of data in each flag category as well as a summary category, TOT, which represents the total percentage of flagged data. The Y indicator in the column labeled "Flagged" indicate those months where data flagged as S, P or U were included in subsequent processing.

Table 5.1

ONSOD Data Summary

MONITOR	DATE	LOP	S/P/U	T	M	L	Q	TOT	FLAGGED
KWAJ	12/76	AD	9.3	0.8	4.6	20.3	9.3	44.2	N
		AH	8.9	0.3	0.1	0	9.7	19.0	N
		DE	9.4	2.2	2.0	15.6	10.8	39.9	N
		EH	9.1	1.6	0.4	0	6.5	17.6	N
KWAJ	1/77	AD	3.1	0.1	6.6	30.2	9.4	49.5	N
		AH	3.0	0	0.4	0	9.4	12.8	N
		EH	3.1	0	0.5	0	8.5	12.1	N
KWAJ	4/77	AC	10.3	1.9	5.6	9.6	10.6	37.9	N
		AE	10.1	1.9	5.6	10.1	12.5	40.3	N
		CE	10.7	0	5.6	0	12.4	28.6	N
		CH	10.0	1.1	6.4	3.5	6.3	27.2	N
		DH	10.7	2.1	5.7	3.2	10.0	31.7	N
		EH	10.0	1.1	5.8	0	10.3	27.2	N
KWAJ	5/77	AC	13.0	0.3	3.5	3.1	13.4	33.3	N
		AE	12.4	0.7	4.0	3.2	14.5	34.8	N
		CE	12.5	0.5	3.8	0	14.5	31.3	N
		CH	11.6	0.1	4.2	0	10.3	26.2	N
		DH	13.0	0	3.6	3.5	7.4	27.6	N
		EH	11.3	0.5	3.4	0	12.6	27.8	N
KWAJ	6/77	AC	11.8	0	8.3	2.8	16.9	39.9	N
		CH	11.3	0	8.9	0	8.9	29.0	N
		DH	11.8	0.3	9.0	6.8	10.8	38.8	N
		EH	7.2	35.4	8.5	0	3.5	54.6	Y
KWAJ	9/77	AC	42.5	0.1	21.3	8.6	2.4	84.9	Y
		AE	42.8	0.3	21.1	16.9	2.8	83.9	Y
		CE	11.7	0.4	21.4	1.9	5.8	41.3	N
		CH	10.3	0.4	21.3	2.4	2.8	37.1	N
		EH	11.4	0.6	20.7	0	7.2	39.9	N

Table 5.1 (Continued)

ONSOD Data Summary

MONITOR	DATE	LOP	S/P/U	T	M	L	Q	TOT	FLAGGED
OROTE	12/75	DH	3.0	0.4	1.5	31.3	8.3	44.5	N
OROTE	1/76	CH	5.4	0	0.4	14.7	12.8	33.2	N
OROTE	2/76	CH	4.0	1.0	0.6	27.5	10.4	43.6	N
		DH	10.6	0.3	0.6	33.6	6.7	41.8	Y
OROTE	3/76	CH	24.7	0	0.5	20.3	5.5	51.1	Y
		DH	30.8	0.1	1.2	33.5	4.4	70.0	Y
OROTE	4/76	CH	25.3	0.1	1.8	14.6	5.7	47.5	N
		DH	28.3	1.4	1.8	31.9	6.7	70.1	Y
OROTE	7/76	AE	2.3	0	21.5	2.7	9.0	35.5	N
		AH	4.8	2.4	9.4	0	6.9	23.5	N
		EH	3.0	3.0	11.7	0	6.6	24.2	N
OROTE	8/76	AE	4.8	0.8	11.0	13.7	7.7	38.0	N
		AH	4.4	0.4	9.4	0	10.2	24.5	N
		EH	4.0	1.3	12.6	0	5.8	23.8	N
OROTE	9/77	AB	53.1	0	14.3	20.6	1.5	89.4	Y
		AE	53.2	0	14.4	20.7	1.4	89.7	Y
		BH	13.3	0.3	14.0	0	6.4	34.0	N
		CE	13.5	0.3	14.2	14.9	4.7	47.5	N
		CH	11.4	0.6	13.3	5.8	6.5	37.6	N
		EH	11.4	0.3	13.8	0	6.8	32.2	N
CLARK	1/76	EH	2.8	3.0	25.4	0	3.5	34.7	N
CLARK	7/76	EH	3.1	3.0	25.4	0	3.8	35.2	N
CLARK	8/76	EH	5.0	0.9	5.9	0	5.6	17.5	N
CLARK	12/76	AB	9.3	0.3	0.9	16.0	6.9	33.3	N
		BE	9.0	1.5	1.2	0	8.2	19.9	N
		EH	6.5	1.5	1.1	0	4.7	13.7	N
CLARK	1/77	AB	3.1	2.7	1.2	22.4	12.9	42.3	N
		BE	3.1	2.7	1.2	0	8.6	15.6	N
		EH	2.3	0	2.4	0	11.0	15.7	N
CLARK	2/77	BE	7.4	0	38.2	0	4.3	50.0	N
		EH	3.7	0	38.4	0	3.3	45.4	N
CLARK	4/77	BE	10.8	0	1.1	3.3	13.9	29.2	N
		EH	8.8	1.1	1.8	0	17.6	29.3	N
CLARK	8/77	AB	7.9	0.3	32.9	5.4	3.9	50.4	Y
		AE	8.1	0.1	32.4	0	5.6	46.2	N
		BE	7.9	0.1	33.1	0	5.0	46.1	N
		CE	8.1	0	33.1	7.5	4.6	53.2	Y
		CH	6.5	0	32.8	8.5	1.9	49.6	N
		EH	5.0	0	33.1	0	3.0	41.0	N

Table 5.1 (Continued)

ONSOD Data Summary

MONITOR	DATE	LOP	S/P/U	T	M	L	Q	TOT	FLAGGED
DARWIN	8/77	AB	1.1	0	91.7	7.2	0	100	Y
		AE	1.1	0	92.1	6.8	0	100	Y
		BH	1.1	0	91.8	7.1	0	100	Y
		CE	1.0	0	91.9	7.1	0	100	Y
		CH	0.6	0	91.7	7.7	0	100	Y
		EH	0.4	0	91.7	7.9	0	100	Y
DARWIN	9/77	AB	7.9	0	88.2	3.9	0	100	Y
		AE	7.6	0	88.9	3.5	0	100	Y
		BH	1.1	0	88.5	10.4	0	100	Y
		CE	1.1	0.3	88.2	10.4	0	100	Y
		CH	0.7	0.3	88.2	10.8	0	100	Y
		EH	0.6	0	88.3	11.1	0	100	Y
DARWIN	10/77	AB	5.8	0.1	87.4	6.7	0	100	Y
		AE	5.5	0.1	87.4	7.0	0	100	Y
		BH	5.9	0.1	87.4	6.6	0	100	Y
		CE	5.9	0	87.6	6.5	0	100	Y
		CH	4.8	0	87.2	7.9	0	100	Y
		EH	5.2	0	87.4	7.4	0	100	Y
PORT MORESBY	8/77	CE	0.9	0	84.4	14.7	0	100	Y
		CH	0.9	0	84.4	14.5	0	100	Y
		EH	0.4	0	84.4	15.3	0	100	Y
PORT MORESBY	9/77	CE	3.2	0.3	66.5	26.5	0.7	97.2	Y
		CH	3.5	0.3	66.8	27.2	0.8	98.6	Y
		EH	2.8	0.3	66.5	26.9	0.7	97.2	Y

Table 5.1 (Concluded)

ONSOD Data Summary

MONITOR	DATE	LOP	S/P/U	T	M	L	Q	TOT	FLAGGED
PORT MORESBY	10/77	CE	6.0	0	76.3	17.6	0	100	Y
		CH	4.6	0	76.1	19.3	0	100	Y
		EH	5.6	0	76.1	18.3	0	100	Y
MIYAK	6/76	AH	3.8	0	0	0	4.6	8.3	N
		CH	3.6	0	0.1	0	5.7	9.4	N
		EH	2.9	0	0.4	0	3.3	6.7	N
MIYAK	7/76	AH	8.3	3.0	0.5	0	8.7	20.6	N
		CH	7.4	3.0	1.1	0	4.8	16.3	N
		EH	3.8	3.0	10.5	0	4.3	21.5	N
MIYAK	8/76	AH	8.6	0.3	1.9	0	7.3	18.0	N
		CH	7.3	0.5	1.2	0	6.5	15.5	N
		EH	7.7	1.2	5.0	0	3.6	17.5	N
MIYAK	9/76	AH	19.7	0.1	0.1	0	6.9	26.9	N
		CH	15.8	0	0.1	0	7.2	23.2	N
		EH	15.8	1.9	0.8	0	1.5	20.1	N
MIYAK	10/76	AH	14.8	0.1	4.0	0	6.9	25.8	N
		CH	12.1	0	9.7	0	5.5	27.3	N
		EH	11.0	1.7	5.4	0	5.0	23.1	N
MIYAK	4/77	AH	10.1	0	6.5	0	5.0	21.7	N
		CH	9.2	0	6.0	0	5.3	20.4	N
		EH	8.8	0	4.9	0	3.2	16.8	N

Data which became available from the flagged data criteria were then examined for geometric considerations. Obvious cases of poor geometry (i.e. LOP crossing angles less than 15° and excess GDOP values) were not analyzed since they could not be employed for navigation purposes. Also, cases where predictions indicated low S/N were not processed unless measured data indicated substantial errors in the prediction of S/N. Next, data from summer and winter periods were selected to allow the best possible comparison with the Omega coverage predictions of Section 5.2.

A number of terms are employed in subsequent analyses of measured data. These terms are defined as follows:

Phase Difference. PHD (h,d). Difference between the phases of signals from two transmitters. The indices h and d are for the hour and the day of the value.

Nominal Phase Difference. LOP. Phase difference computed at a position, using chart velocity.

Predicted Phase Difference. PHDp (h,d). Phase difference at a position, predicted from models or measurements.

Propagation Correction. PPC (h,d). Difference between the predicted phase difference at a position and the nominal phase difference.

$$PPC\ (h,d) = LOP - PHDp\ (h,d)$$

Observed Phase Difference. PHDo (h,d). Measurement of a phase difference from a receiver.

Corrected Phase Difference. PHDc (h,d). Sum of the observed phase difference and the propagation correction.

$$PHDc\ (h,d) = PHDo\ (h,d) + PPC\ (h,d)$$

Phase Difference Error. Ephd (h,d). Difference between the observed phase difference and the predicted phase difference.

$$Ephd\ (h,d) = PHDo\ (h,d) - PHDp\ (h,d)$$

$$Ephd\ (h,d) = PHDo\ (h,d) + PPC\ (h,d) - LOP$$

$$Ephd\ (h,d) = PHDc\ (h,d) - LOP$$

Position Component Errors. $E_n(h,d)$. $E_e(h,d)$. North and east components of position errors.

Radial Error. $E_r(h,d)$. Magnitude of the error vector.

$$E_r(h,d) = \sqrt{E_n^2(h,d) + E_e^2(h,d)}$$

Hourly Mean Phase Difference Error. Ephd(h). Average value, over the month of the phase difference error. D is the number of days for which there is data.

$$\mathrm{Ephd}(h) = \frac{1}{D} \sum_{d=1}^{D} \mathrm{Ephd}(h,d)$$

Hourly Standard Deviation of the Phase Difference Error. $SD_{ephd}(h)$. Standard deviation of the phase difference errors about the hourly mean phase difference errors.

$$SD_{ephd}(h) = \sqrt{\frac{1}{D} \sum_{d=1}^{D} (E_{phd}(h,d) - E_{phd}(h))^2}$$

Hourly Mean Position Component Errors. $E_n(h)$. $E_e(h)$. Average value, over the month, of the position component errors.

$$E_n(h) = \frac{1}{D} \sum_{d=1}^{D} E_n(h,d)$$

$$E_e(h) = \frac{1}{D} \sum_{d=1}^{D} E_e(h,d)$$

Hourly Mean Radial Error. $E_r(h)$. Average value, over the month, of the radial error.

$$E_r(h) = \frac{1}{D} \sum_{d=1}^{D} E_r(h,d)$$

Hourly Standard Deviation of the Radial Error. SD(h). Standard deviation of the radial errors about the hourly mean radial errors.

$$SD(h) = \sqrt{\frac{1}{D} \sum_{d=1}^{D} (E_n(h,d) - E_n(h))^2 + (E_e(h,d) - E_e(h))^2}$$

Maximum Radial Error. $E_r(M)$. Maximum value of the hourly mean radial errors. M is the hour the maximum value occurs.

Maximum Standard Deviation. SD(M). Maximum value, over the hours, of the hourly standard deviations.

Mean Radial Error. ME_r. Average value, over the hours, of the hourly mean radial errors. H is the number of hours for which there is data.

$$ME_r = \frac{1}{H} \sum_{h=1}^{H} E_r(h)$$

Mean Standard Deviation of the Radial Error. MSD. Average value, over the hours, of the hourly standard deviation.

$$MSD = \frac{1}{H} \sum_{h=1}^{H} SD(h)$$

Errors in the signal measurements cause position errors which depend on geometry. This is known as geometrical dilution of precision (GDOP). Hyperbolic GDOP is defined as the ratio of RMS position error to the RMS position error of "ideal" geometry, assuming equal RMS errors on all received phases. For Omega hyperbolic geometry, the "ideal" configuration is represented by four stations at multiples of 90° in bearing from the receiver.

For four stations forming LOPs A and B, GDOP is

$$GDOP_4 = \frac{2}{\sqrt{2}} \frac{1}{\sin\theta_4} \sqrt{\frac{1}{|\nabla LOPA|^2} + \frac{1}{|\nabla LOPB|^2}}$$

where θ_4 is the crossing angle of the two LOPs and $|\Delta LOPA|$ is the magnitude of the gradient of the LOP. θ_4 can be found from

$$\theta_4 = \frac{BR1 - BR2}{2} + \frac{BR3 - BR4}{2}$$

where BR1 through BR4 are the bearing angles to the four stations used in the position fix. The magnitude of the gradient is found from

$$|\nabla LOPA| = 2\sin\left(\frac{BR1 - BR2}{2}\right) \qquad |\Delta LOPB| = 2\sin\left(\frac{BR3 - BR4}{2}\right)$$

For three stations GDOP becomes

$$GDOP_3 = \frac{2}{\sqrt{2}} \frac{1}{\sin\theta_3} \sqrt{\frac{1}{|\nabla LOPA|^2} + \frac{1}{|\nabla LOPB|^2} + \frac{\cos\theta_3}{|\nabla LOPA||\nabla LOPB|}}$$

where θ_3 is the crossing angle of the LOPs given by

$$\theta_3 = \frac{BR1 - BR2}{2} + \frac{BR2 - BR3}{2}$$

where BR1 through BR3 are the bearing angles to the three stations in the triad, the magnitude of the gradients is

$$|\Delta LOPA| = 2\sin\left(\frac{BR1 - BR2}{2}\right) \qquad |\Delta LOPB| = 2\sin\left(\frac{BR2 - BR3}{2}\right)$$

5.3.2 Kwajalein Data

Data from the ONSOD monitoring site at Kwajalein, Marshall Islands, which passed the selection criteria described in Section 5.3.1, were processed and presented in a series of graphs. These graphs are provided in Appendix A. A summary of the graphs provided in Appendix A is contained in Table 5.2.

A representative set of graphs from Appendix A is shown in Figures 5.3 through 5.8. These graphs illustrate the type of data in the appendix, and they are examples of the primary output obtained from the ONSOD Kwajalein master file. The representative set consists of six plots as follows:

(1) Figures 5.3 and 5.5 are graphs of the hourly averages over a month of the observed phase difference for Omega LOPs DE and EH. Also indicated on the graphs are the nominal LOPs which are used as a reference for later analyses. A D or N indicator placed under the hour on the GMT axis indicates those times when full-day or full-night propagation paths existed simultaneously to both transmitters.

(2) Figures 5.4 and 5.6 are graphs of the mean hourly phase difference error. These plots are derived from the measured data shown in Figures 5.3 and 5.5 by incorporating PPC values and referencing the measured data to the nominal LOP for the Kwajalein site. The standard deviation of the data about the mean values is also shown.

(3) Figures 5.7 and 5.8 are graphs of the mean hourly east/west and mean north/south errors based on the LOPs DE and EH. The standard deviation about the mean is also shown on the plots.

The representative set for Kwajalein is based on DE and EH LOP data recorded at 10.2 kHz in January 1977. The graphs were plotted only for those hours where sufficient data were available. As can be seen in Figure 5.3, sufficient data were not available for GMT hours 1, 13, and 16 through 24 for LOP DE.

Table 5.2
Kwajalein Processed Data

TYPE OF PLOT	FREQUENCY (kHz)	STATIONS
OBSERVED PHASE DIFFERENCE	10.2	
JAN. 1977		AD, AH, DE & EH
SEPT. 1977		CE, CH & EH
PHASE DIFFERENCE ERROR		
JAN. 1977		AD, AH, DE & EH
SEPT. 1977		CE, CH & EH
POSITION FIX ERROR		
JAN. 1977		AD-AH, AD-DE, AD-EH, AH-EH & DE-EH
SEPT. 1977		CE-CH, CE-EH & CH-EH

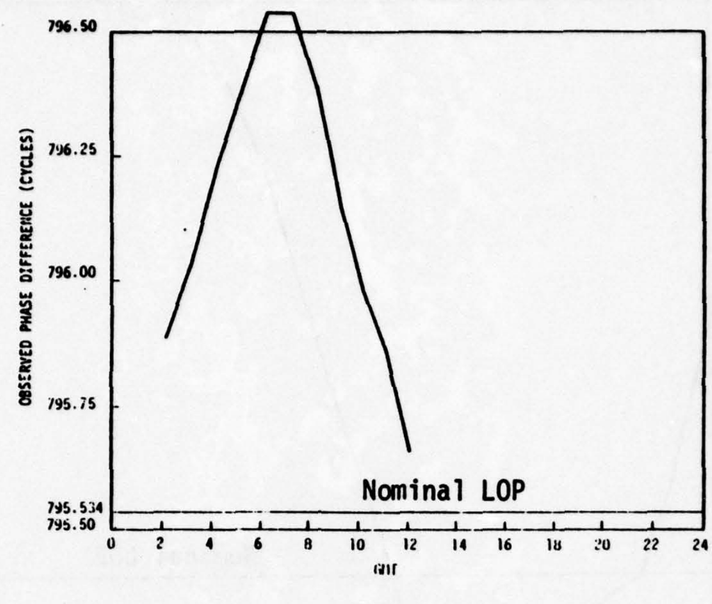

Figure 5.3 Observed Phase Difference, Kwajalein, DE, 10.2, 1/77

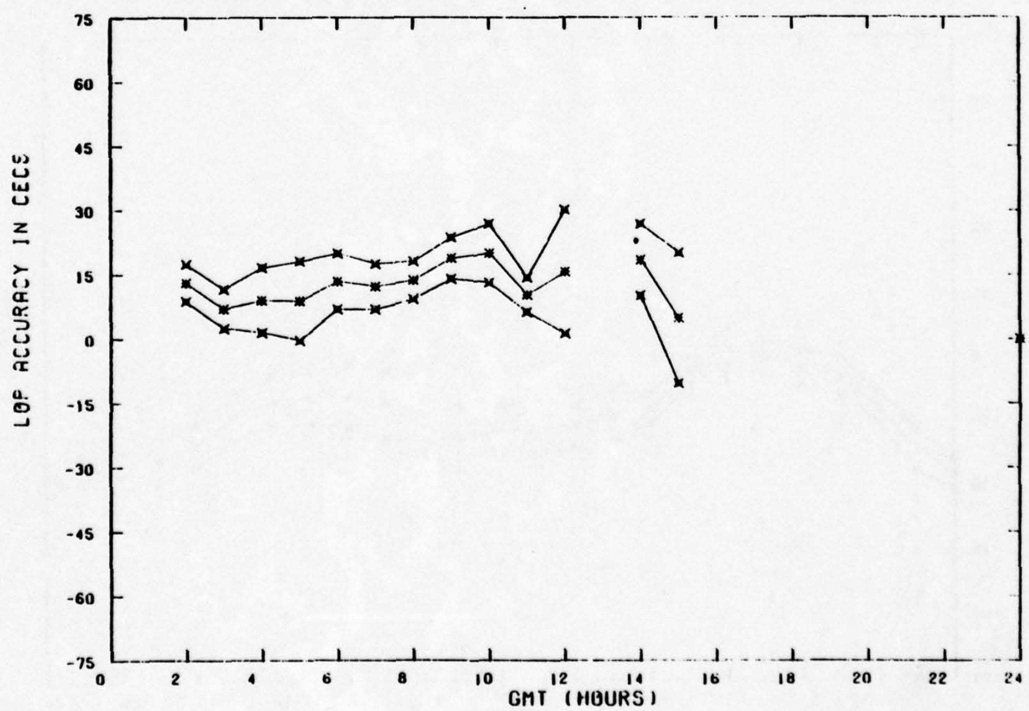

Figure 5.4 Phase Difference Error, Kwajalein, DE, 10.2, 1/77

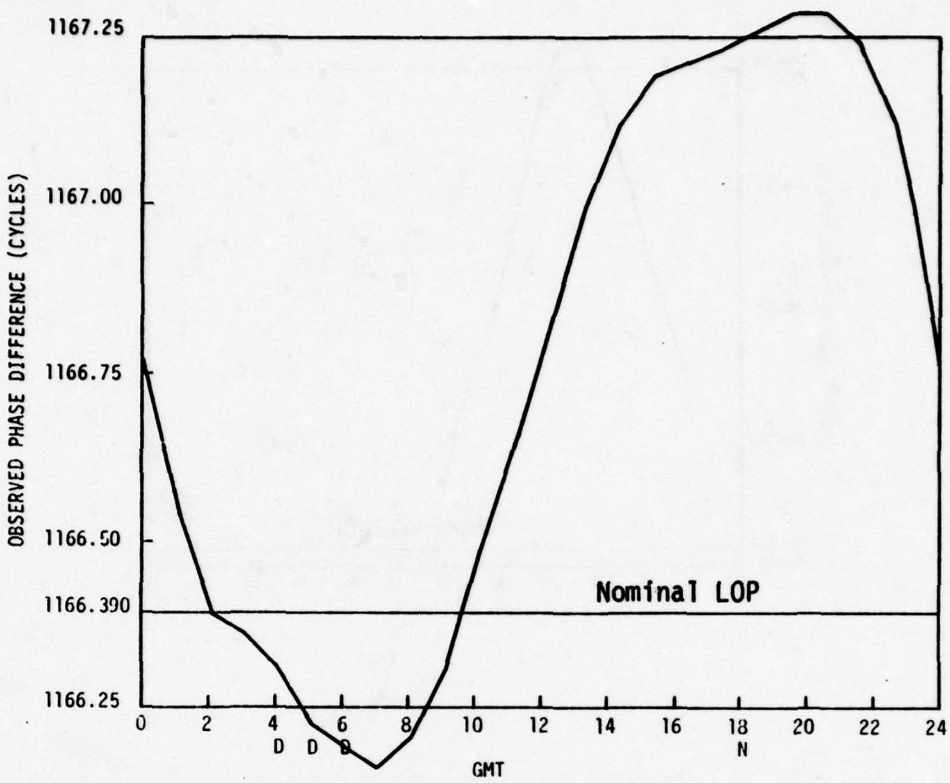

Figure 5.5 Observed Phase Difference, Kwajalein, EH, 10.2, 1/77

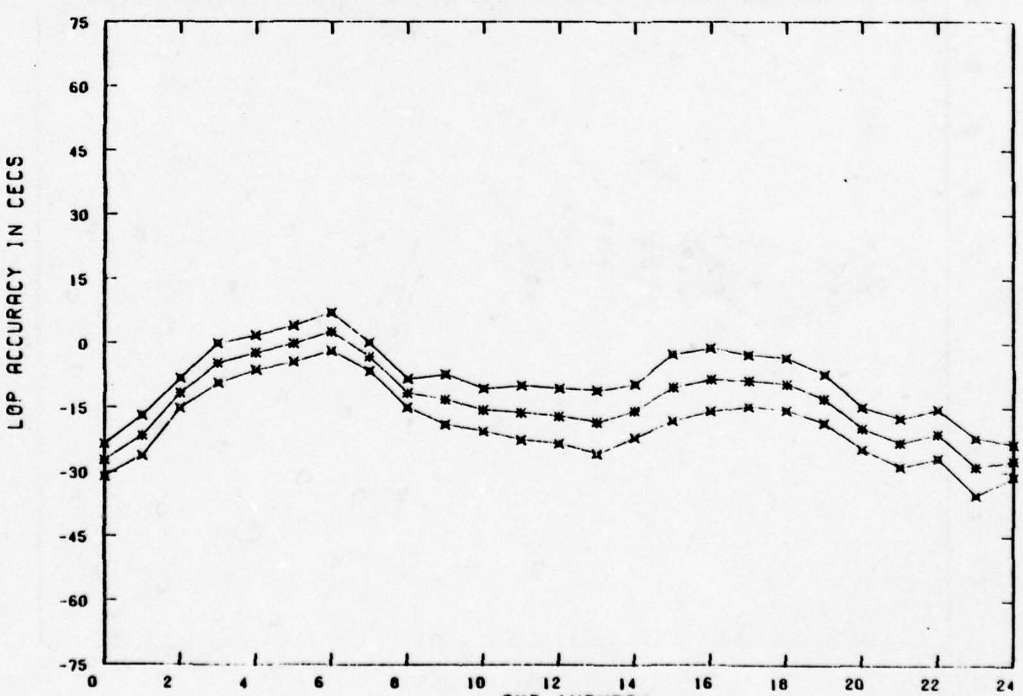

Figure 5.6 Phase Difference Error, Kwajalein, EH, 10.2, 1/77

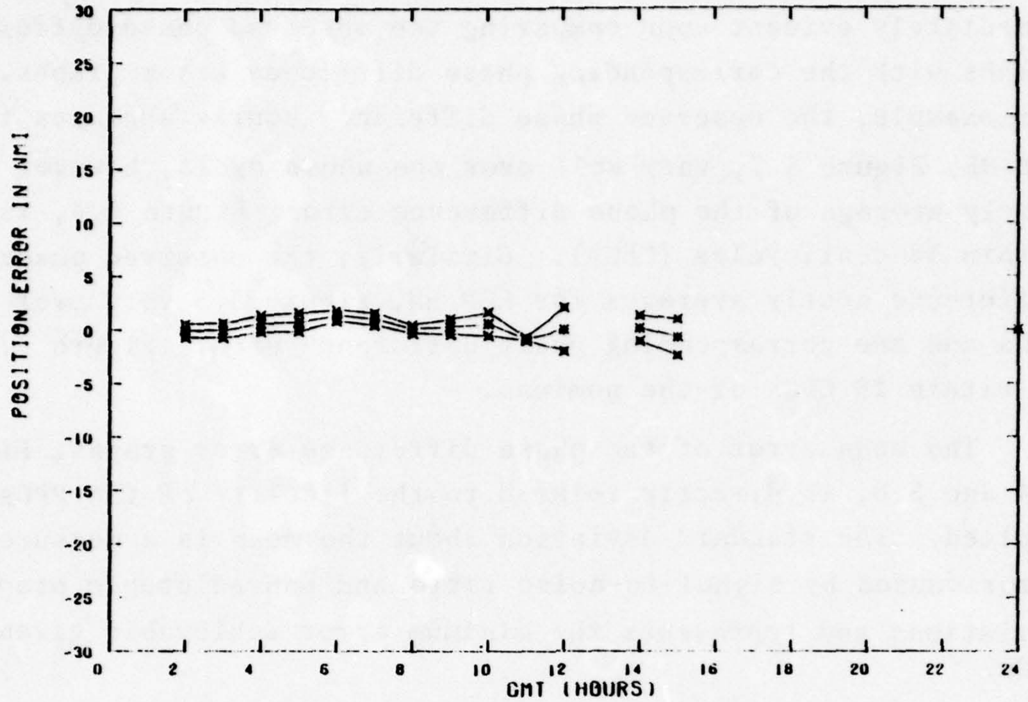

Figure 5.7 East Position Error, Kwajalein, DE-EH, 10.2, 1/77

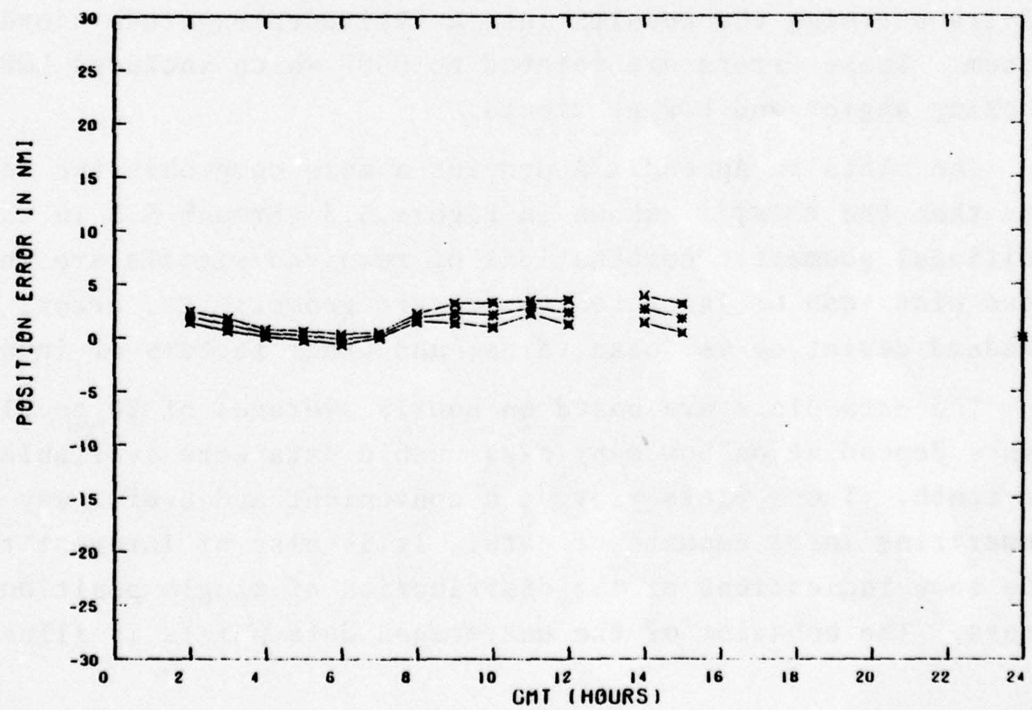

Figure 5.8 North Position Error, Kwajalein, DE-EH, 10.2, 1/77

The effects of applying the PPCs to the measurements is immediately evident upon comparing the observed phase difference graphs with the corresponding phase difference error graphs. For example, the observed phase difference hourly averages for LOP DE, Figure 5.3, vary well over one whole cycle, however the hourly average of the phase difference error, Figure 5.4, is within 18 centicycles (CECs). Similarly, the observed phase difference hourly averages for LOP EH, Figure 5.5 vary over 110 CECs and the corresponding phase difference error, Figure 5.6, is within 28 CECs of the nominal.

The mean error of the phase difference error graphs, Figures 5.4 and 5.6, is directly related to the fidelity of the PPCs applied. The standard deviation about the mean is a measure of error caused by signal-to-noise ratio and unpredictable propagation variations and represents the minimum error achievable given perfect PPCs.

The east/west (Figure 5.7) and north/south (Figure 5.8) position fix errors are the result of combining the two LOP errors and transforming the results into a latitude/longitude coordinate system. These errors are related to GDOP which includes LOP crossing angles and LOP gradients.

The plots in Appendix A provide a more comprehensive set of data than the examples shown in Figure 5.3 through 5.8 in that additional geometric combinations of received signals are included. These plots can be inspected to compare geometry vs. error, the standard deviation vs. mean value, and other factors of interest.

The data plots are based on hourly averages of 10 to 31 data points depending on how many days usable data were available during the month. These plots provide a convenient and useful way of summarizing large amounts of data. It is also of interest to provide some indications of the distribution of single position fix errors. The behavior of the unaveraged data points is illustrated

in the scatter diagram shown in Figure 5.9. Rather than plot up to 700 points for the monthly data, a representative sample was selected by taking a single point for each hour but each for a different day. The points were selected by taking a diagonal through the 24-hour x 30-day monthly data block of position errors after PPCs have been applied. Such a sample tends to avoid single-day or single-hour biases. A circle containing 95% of the points plotted has been placed on the scatter diagram. If less than 20 points were used, all of the data is included within the circle. The 95% circle is about the data with the mean errors removed.

Table 5.3 provides a summary of Kwajalein position fixing errors. The table lists the data according to increasing geometric dilution of precision (GDOP). GDOP is a measure of the quality of the station geometry used. The smallest GDOP value is for the best geometry. The maximum radial error is the maximum of the hourly mean value of all unflagged data at the same hour for the month. This value gives the upper limit of the expected average error. The hour and the direction of the maximum radial error is also included in Table 5.3. The maximum hourly standard deviation is a measure of the upper limit of the expected variation about the hourly mean. The hour of the maximum standard deviation is included. The mean radial error is the average value of the square root of the sum of the squares of the hourly mean errors. This gives a measure of the expected radial error. The mean standard deviation is a measure of the variation about the hourly mean errors.

Table 5.3

Error Summary of Kwajalein LOP Data, 10.2 kHz

LOP PAIR	DATE MONTH/YEAR	LOP CROSSING ANGLE	GDOP	MAX RADIAL ERROR			MAX STANDARD DEVIATION		MEAN RADIAL ERROR N.M.	MEAN STANDARD DEVIATION N.M.
				N.M.	DIREC-TION	HOUR GMT	N.M.	HOUR GMT		
CH-EH	9/77	87.2°	1.64	4.4	7°	23	1.6	12	2.1	.8
CE-CH	9/77	30.8°	1.64	4.4	7°	23	1.7	17	2.1	.8
CE-EH	9/77	56.4°	1.64	4.4	7°	23	1.7	12	2.2	.8
DE-EH	1/77	45.7°	1.85	3.0	344°	11	2.3	12	1.8	1.2
AD-DE	1/77	49.6°	1.96	8.6	333°	8	3.2	6	3.9	1.6
AD-EH	1/77	84.8°	2.10	7.4	315°	21	2.1	8	3.0	1.4
AH-EH	1/77	49.6°	3.87	8.4	98°	7	3.9	19	3.3	2.9
AD-AH	1/77	45.7°	4.34	11.2	3°	7	5.6	8	4.2	3.27

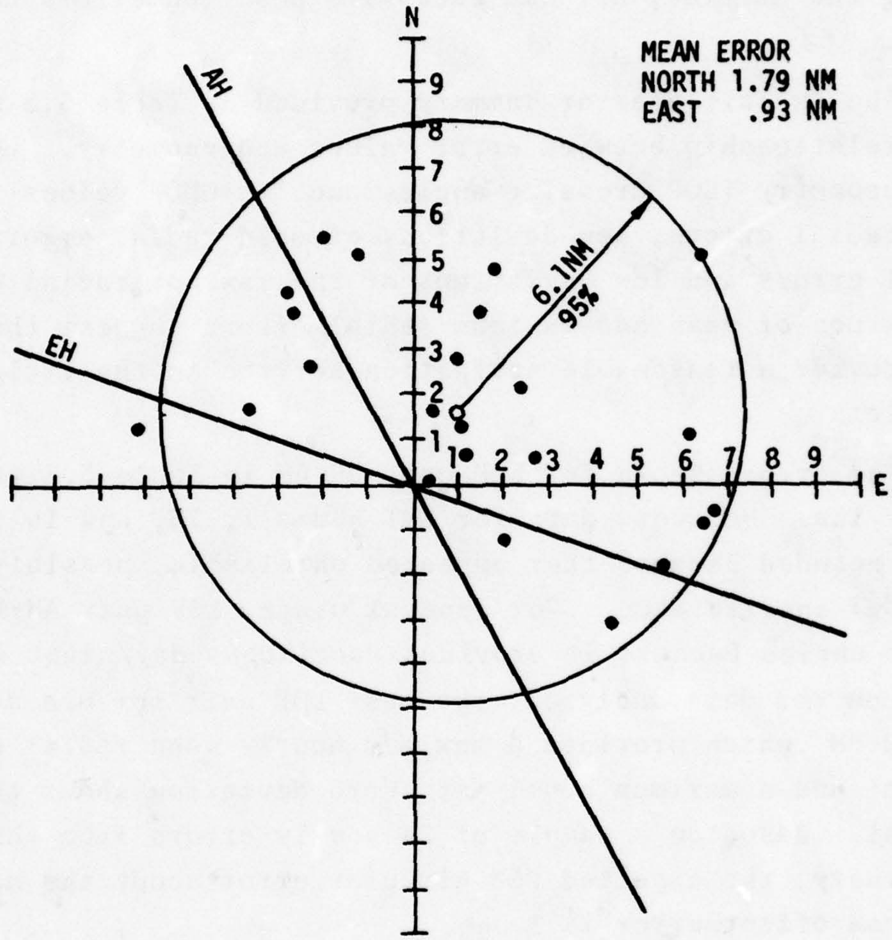

Figure 5.9 Scatter Diagram of Position Errors Observed, Kwajalein, AH-EH, 10.2 kHz, January 1977

Comments on Kwajalein Data:

Data analyzed from the ONSOD Kwajalein site were generally in accord with expectations. The continuous reception of signals from Omega transmitting stations A, H and E at 10.2 kHz were confirmed. Station C was shown to be a reliable alternate except during day/night transitions. Station D provided reliable reception during the daytime, but had excessive position errors during the night.

The Kwajalein error summary provided in Table 5.3 shows a firm relationship between error values and geometry. LOP pairs with good geometry (LOP crossing angles and low GDOP values) gave low mean radial errors, low deviations of mean radial error, low maximum radial errors and low deviations of the maximum radial error. The values of mean and maximum radial errors suggest that Omega can provide a reasonable navigation service in the vicinity of Kwajalein.

The errors shown for LOP pair DE-EH in Table 5.3 are relatively low. However, data for GMT hours 1, 13, and 16 through 24 were excluded because they appeared unreliable, possibly because of modal interference. For general usage, LOP pair AH-EH is a better choice because it provides continuous day/night coverage. Based on the data analyzed, the best LOP pair for use at Kwajalein is AH-EH which provided a maximum hourly mean radial error of 8.4 nmi and a maximum hourly standard deviation about the mean of 3.9 nmi. Based on a sample of 24 hourly errors from the month of January, the expected 95% circular error about the mean is 6.7nm The mean offset error is 2.0nm.

5.3.3 Orote Point Data

Data from Orote Point which was analyzed is summarized in Table 5.5. The resulting graphs are presented in Appendix B. A representative set of plots of Orote Point data from Appendix B is shown in Figures 5.10 through 5.15. These plots and the scatter diagram of Orote Point data (Figure 5.16) and the summary of Orote Point data given in Table 5.5 follow the sequence and

Table 5.4
Orote Point Processed Data

TYPE OF PLOT	FREQUENCY (kHz)	STATIONS
OBSERVED PHASE DIFFERENCE		
FEB. 1976		CH & DH
SEPT. 1977		CE, CH & EH
PHASE DIFFERENCE ERROR		
FEB. 1976		CH & DH
JULY 1976	10.2	AE, AH & EH
SEPT. 1977		BH, CE, CH & EH
POSITION FIX ERROR		
FEB. 1976		CH-DH
JULY 1976		AE-AH & AH-EH
SEPT. 1977		BH-EH, CE-CH, CH-EH & CE-EH
PHASE DIFFERENCE ERROR		
JULY 1976		AE, AH & EH
MARCH 1976	13.6	CH & DH
POSITION FIX ERROR		
JULY 1976		AE-AH & AH-EH
MARCH 1976		CH-DH

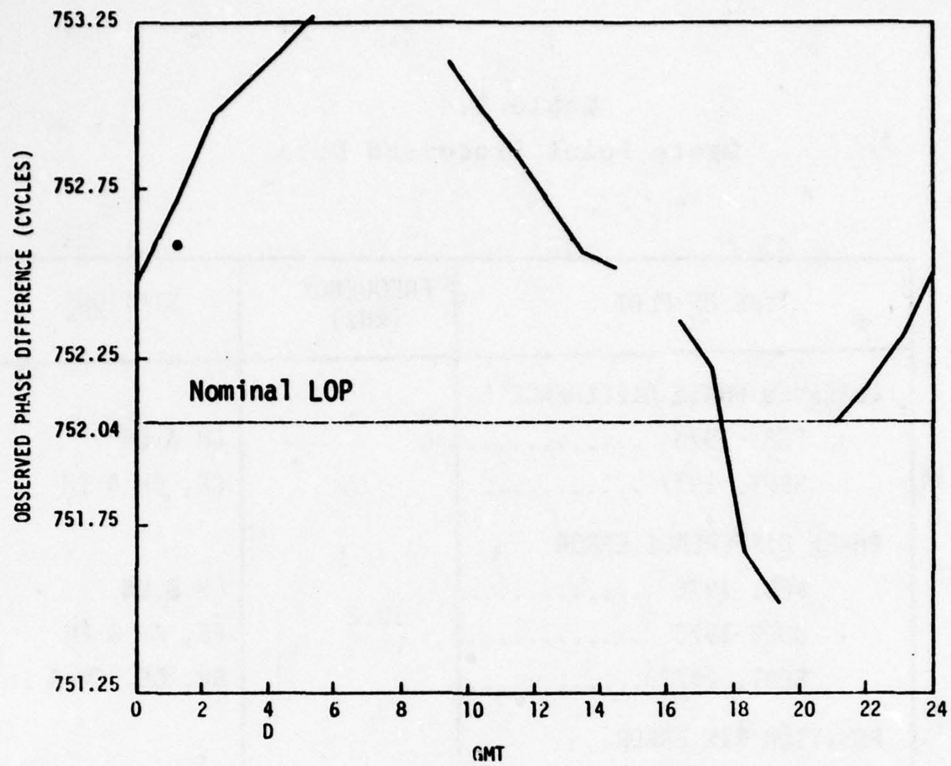

Figure 5.10 Observed Phase Difference, Orote, CE, 10.2, 9/77

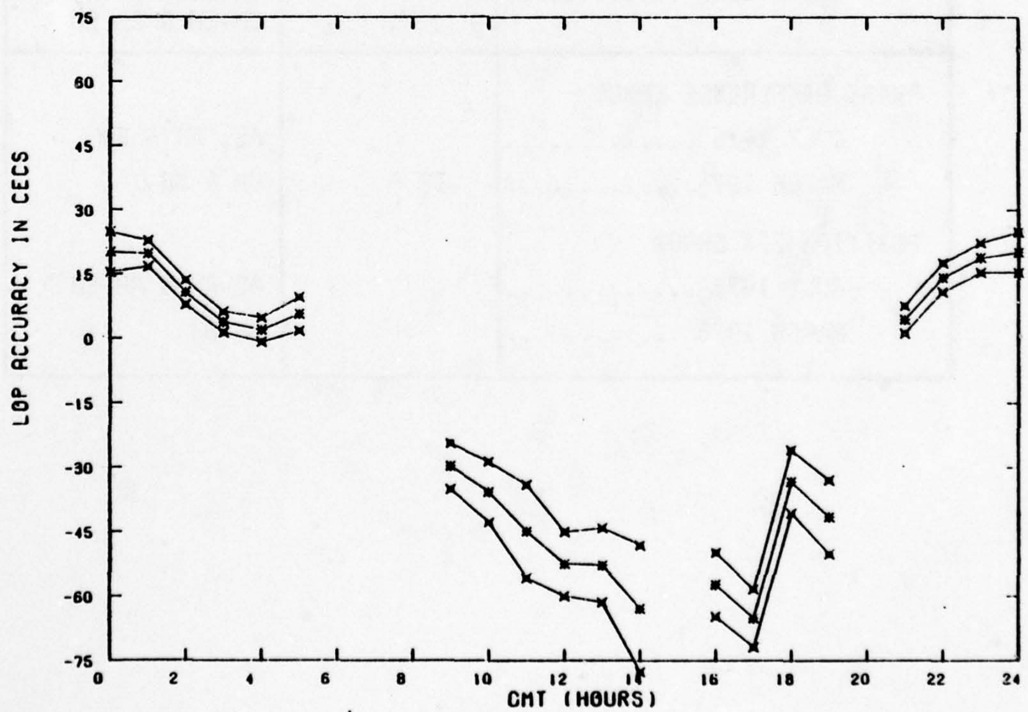

Figure 5.11 Phase Difference Error, Orote, CE, 10.2, 9/77

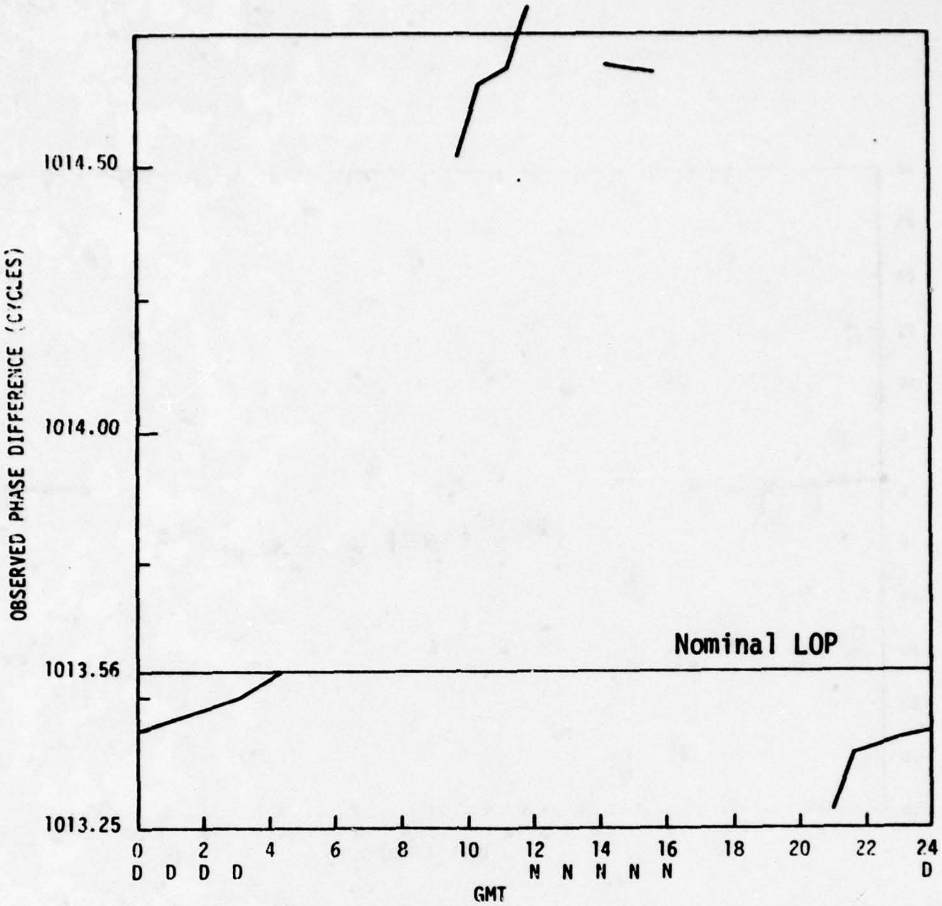

Figure 5.12 Observed Phase Difference, Orote, CH, 10.2, 9/77

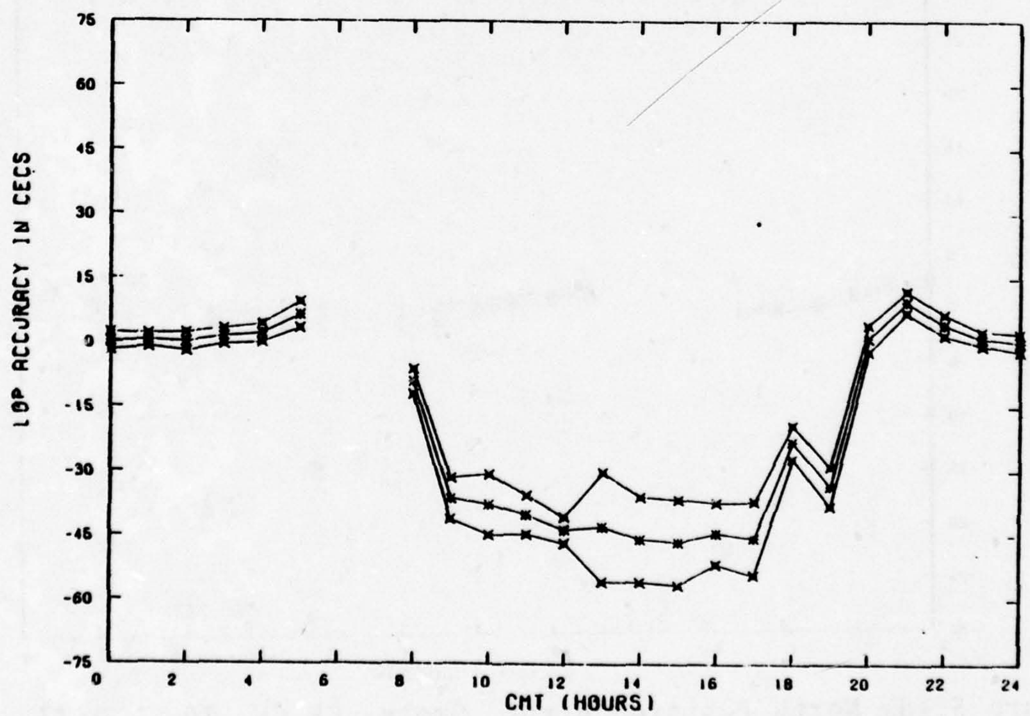

Figure 5.13 Phase Difference Error, Orote, CH, 10.2, 9/77

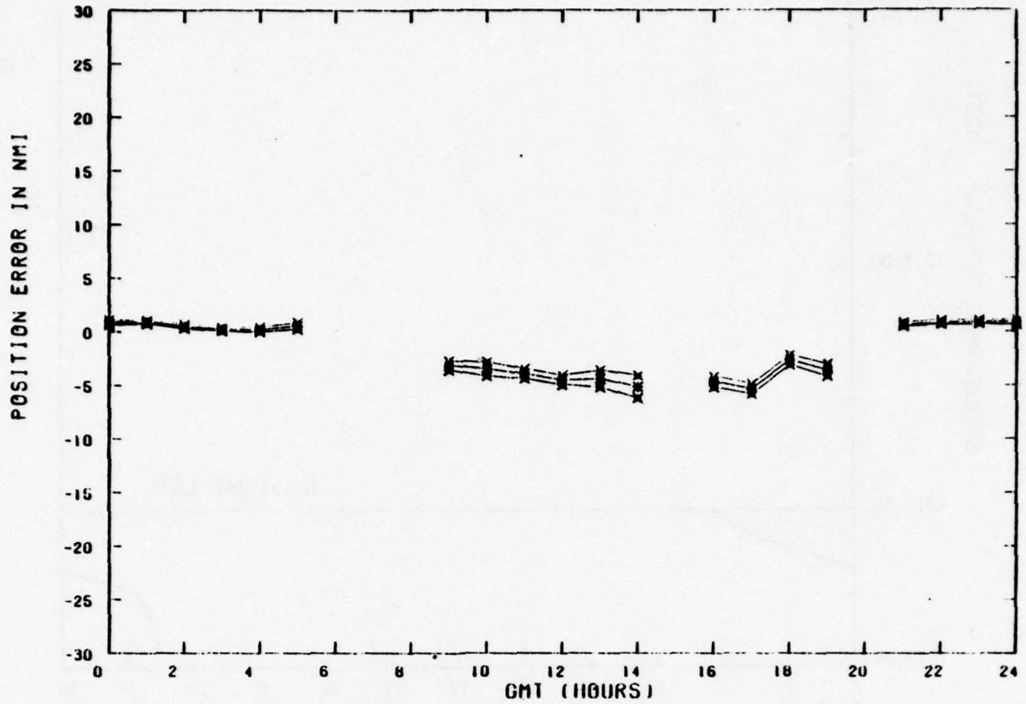

Figure 5.14 East Position Error, Orote, CE-CH, 10.2, 9/77

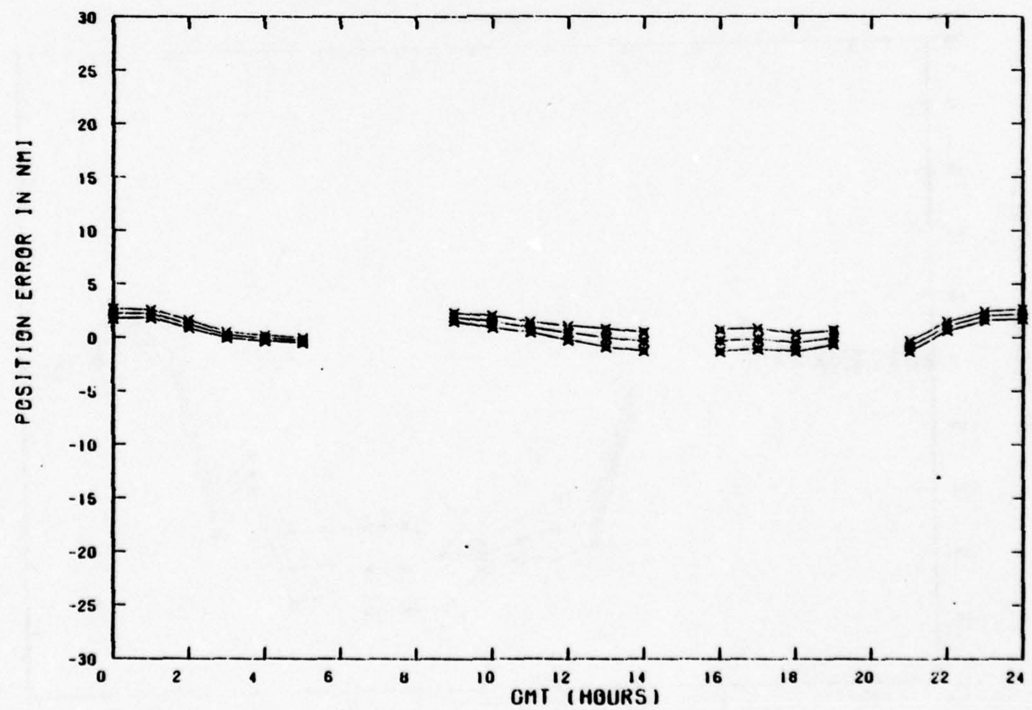

Figure 5.15 North Position Error, Orote, CE-CH, 10.2, 9/77

Table 5.5

Error Summary of Orote Point LOP Data, 10.2 kHz

LOP PAIR	DATE MONTH/ YEAR	LOP CROSSING ANGLE	GDOP	MAX RADIAL ERROR			MAX STANDARD DEVIATION		MEAN RADIAL ERROR N.M.	MEAN STANDARD DEVIATION N.M.
				N.M.	DIREC- TION	HOUR GMT	N.M.	HOUR GMT		
CE-CH	9/77	39.8°	1.41	5.4	269°	17	1.4	14	2.8	.7
CH-EH	9/77	88.2°	1.41	5.4	263°	15	1.5	13	2.8	.7
CE-EH	9/77	52.1°	1.41	5.5	270°	17	1.4	14	2.8	.7
AH-EH	7/76	46.6°	9.17	40.2	114°	20	12.8	8	15.2	8.2
AE-AH	7/76	40.0°	9.26	39.5	114°	20	13.9	8	15.7	7.9

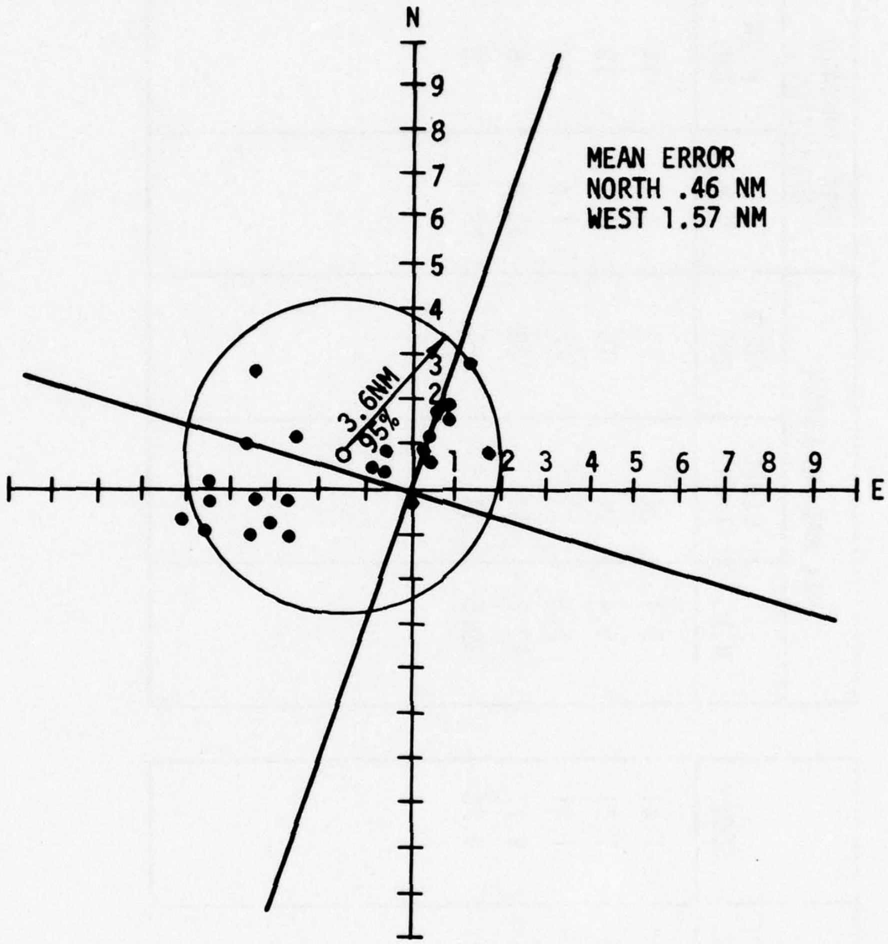

Figure 5.16 Scatter Diagram of Position Errors Observed, Orote Point, CH-EH, 10.2 kHz, 9/77

definitions described in Section 5.3.2 for Kwajalein data. LOP pairs CE and CH for September 1977 are employed in the examples used in Figures 5.10 through 5.15.

Comments on Orote Point Data

At Orote Point, the data confirm continuous coverage from Stations A, E and H at 10.2 kHz. While Station A provides signal coverage, the location is near the AH baseline extension so that both Stations A and H cannot be used in a three-station position fix. Station C provides daytime coverage and Station D provides coverage at night. During the day/night transition, a third reliable station for position fixing may not be available.

From the summary table it can be seen that a good position fix is provided by LOPs CH-EH when the signal is reliably received. Data was not available for LOPs DE-EH. LOP AE-AH data shows very large errors due to the location near the AH baseline extension.

Based on the data analyzed, the best LOP pair for use at Orote Point is DH-EH which provided an estimated maximum hourly mean radial error of 5.5 nmi and an estimated maximum hourly standard deviation about the mean of 1.5 nmi. Based on a sample of 23 hourly errors from the month of September on LOP CH-EH, the expected 95% circular error about the mean is 3.6 nmi. The mean offset error is 1.63 nmi. The bimodal characteristics of the errors of the CH-EH Orote Point position fixes are clearly visible from the scatter diagram. The points grouped to the east are for local daytime. If the sample points are analyzed separately for local daytime and local nighttime the 95% circular error about the mean is 2.0 nmi for daytime and 2.5 nmi for nighttime.

5.3.4 Clark Data

Data from Clark which was analyzed is summarized in Table 5.6. The resulting graphs are presented in Appendix C. A representative set of plots of Clark Air Base data is shown in Figures

5.17 through 5.22. These plots and the scatter diagram of Clark data (Figure 5.23) and the summary of Clark data given in Table 5.7 follow the sequence and definitions described in Section 5.3.2 for Kwajalein data. LOP pairs AB and BE for August 1977 are employed in the examples used in Figures 5.17 through 5.22.

Comments on Clark Data:

Data analyzed from the ONSOD Clark Air Base site were generally in accord with expectations. The continuous reception of signals from Omega transmitting stations A, B, E and H at 10.2 kHz was

Table 5.6
Clark Processed Data

TYPE OF PLOT	FREQUENCY (kHz)	STATIONS
OBSERVED PHASE DIFFERENCE	10.2	
JAN. 1977		AB, BE & EH
AUG. 1977		AB, AE, BE & CH
PHASE DIFFERENCE ERROR		
JULY 1976		BE & EH
JAN. 1977		AB, BE & EH
AUG. 1977		AB, AE, BE & CH
POSITION FIX ERROR		
JULY 1976		BE-EH
JAN. 1977		AB-BE & BE-EH
AUG. 1977		AB-AE, AB-BE, AB-CH, AE-BE, AE-CH & BE-CH
PHASE DIFFERENCE ERROR	13.6	
JULY 1976		AB, BE & EH
POSITION FIX ERROR		
JULY 1976		AB-BE & BE-EH

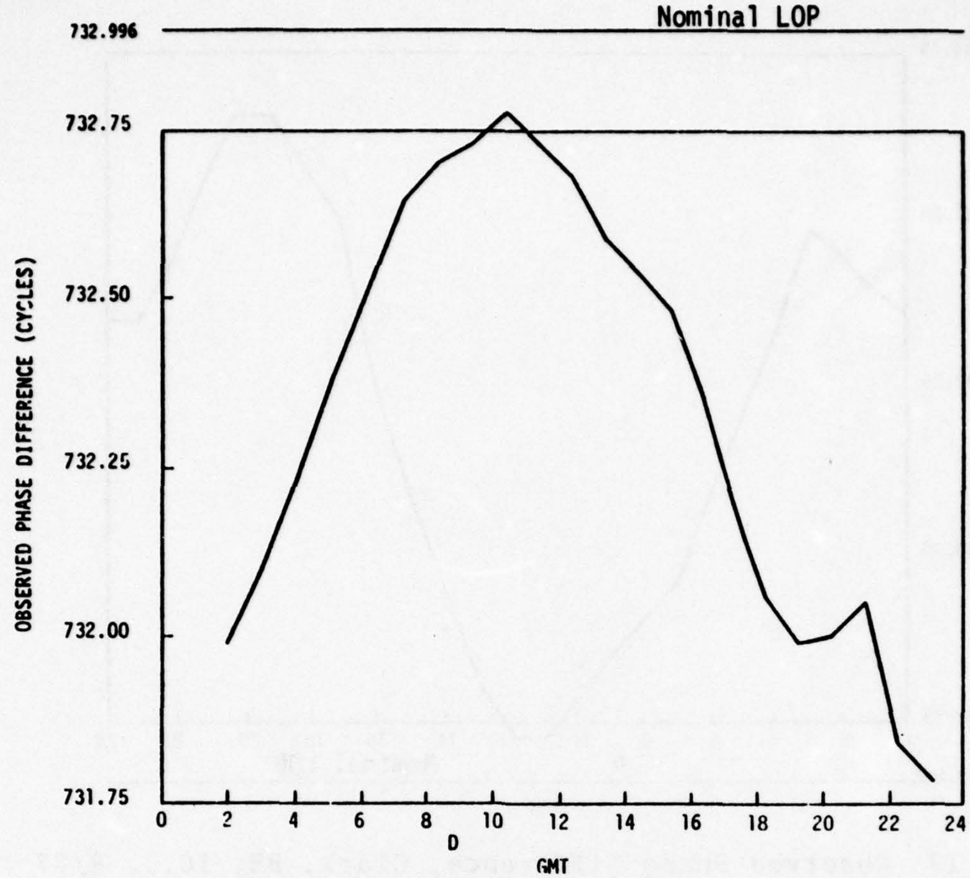

Figure 5.17 Observed Phase Difference, Clark, AB, 10.2, 8/77

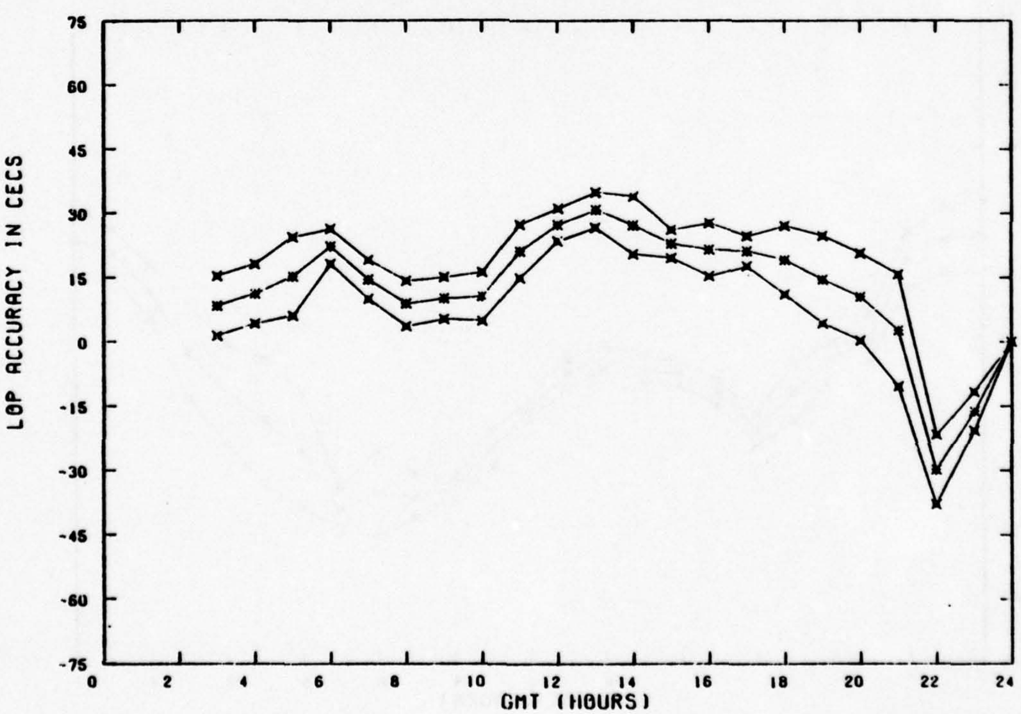

Figure 5.18 Phase Difference Error, Clark, AB, 10.2, 8/77

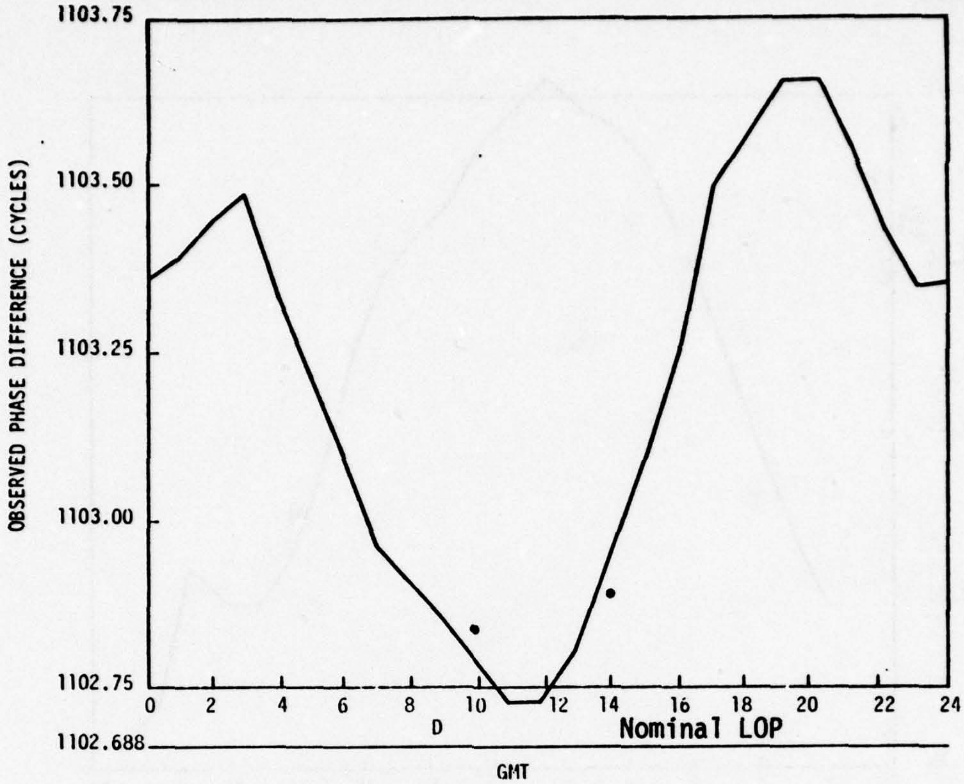

Figure 5.19 Observed Phase Difference, Clark, BE, 10.2, 8/77

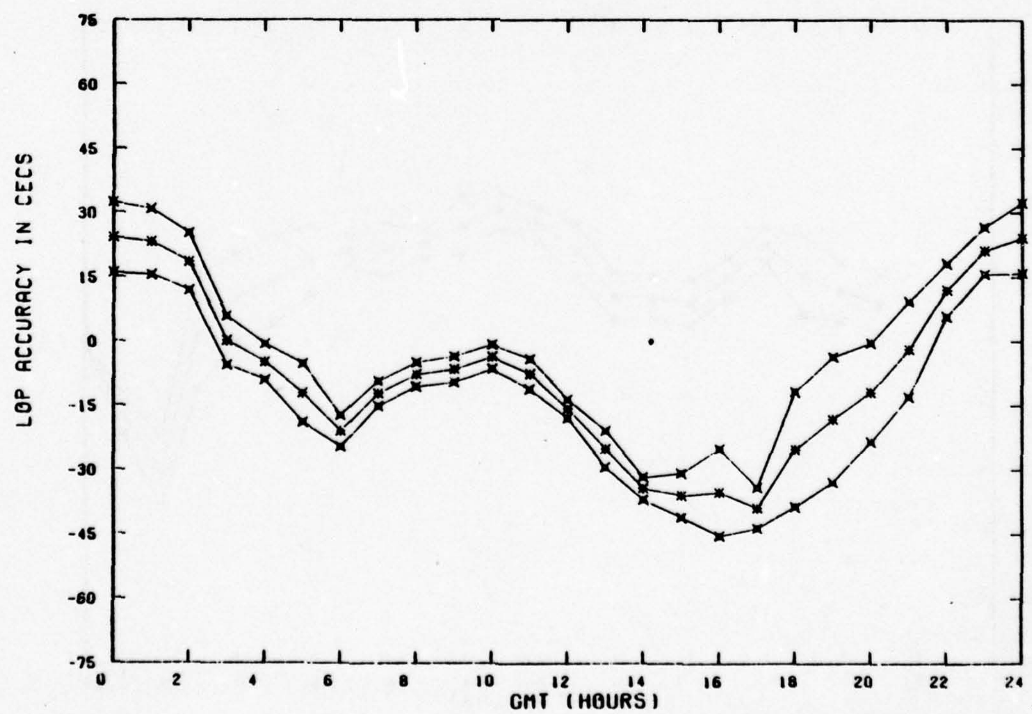

Figure 5.20 Phase Difference Error, Clark, BE, 10.2, 8/77

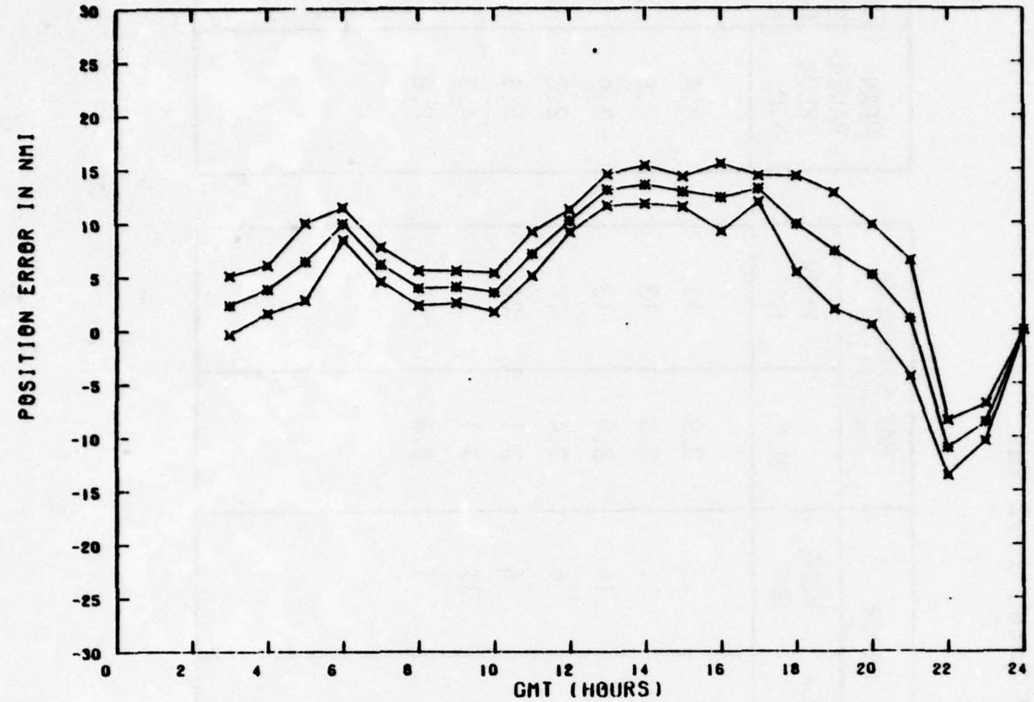

Figure 5.21 East Position Error, Clark, AB-BE, 10.2, 8/77

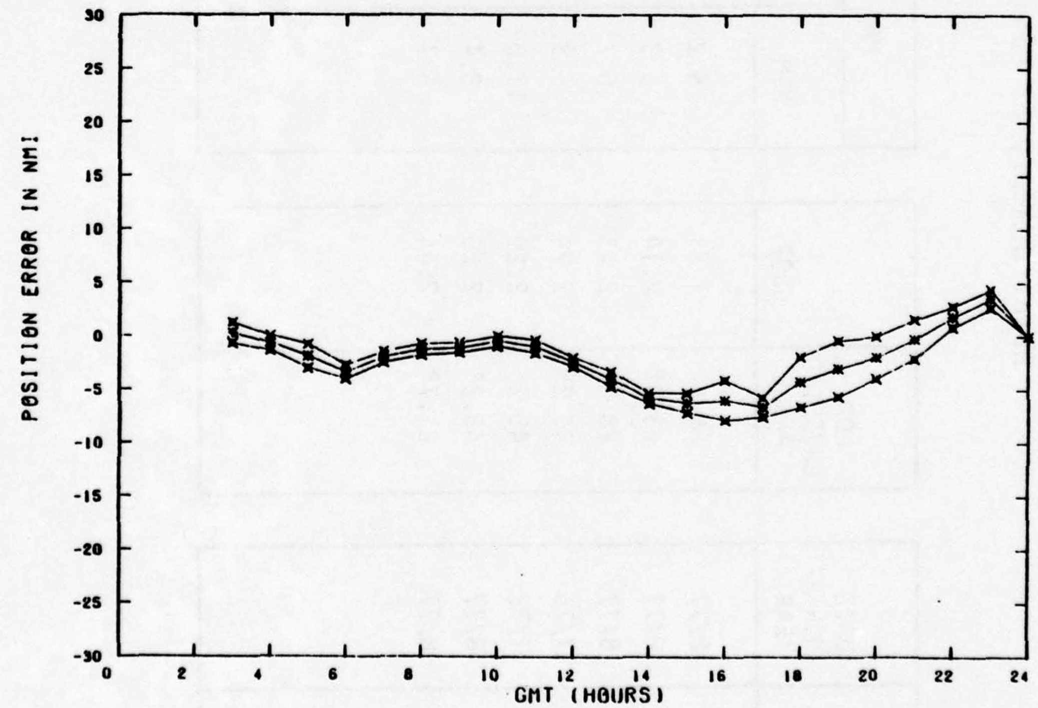

Figure 5.22 North Position Error, Clark, AB-BE, 10.2, 8/77

Table 5.7

Error Summary of Clark LOP Data, 10.2 kHz

LOP PAIR	DATE MONTH/ YEAR	LOP CROSSING ANGLE	GDOP	MAX RADIAL ERROR			MAX STANDARD DEVIATION		MEAN RADIAL ERROR N.M.	MEAN STANDARD DEVIATION N.M.
				N.M.	DIREC- TION	HOUR GMT	N.M.	HOUR GMT		
CH-EH	8/77	85.6°	1.81	5.2	317°	11	2.9	13	2.4	1.1
AE-CH	8/77	63.9°	2.14	5.3	307°	11	3.3	13	2.8	1.2
AB-CH	8/77	88.0°	2.43	6.7	54°	14	2.9	13	3.9	1.5
BE-EH	7/76	45.2°	2.29	6.3	127°	6	3.4	17	2.8	2.3
BE-EH	1/77	45.2°	2.29	11.0	130°	6	3.1	24	5.3	1.7
BE-EH	8/77	45.2°	2.29	8.4	151°	17	3.1	19	4.3	1.5
AE-EH	8/77	21.7°	2.44	5.7	331°	1	3.6	24	2.8	1.6

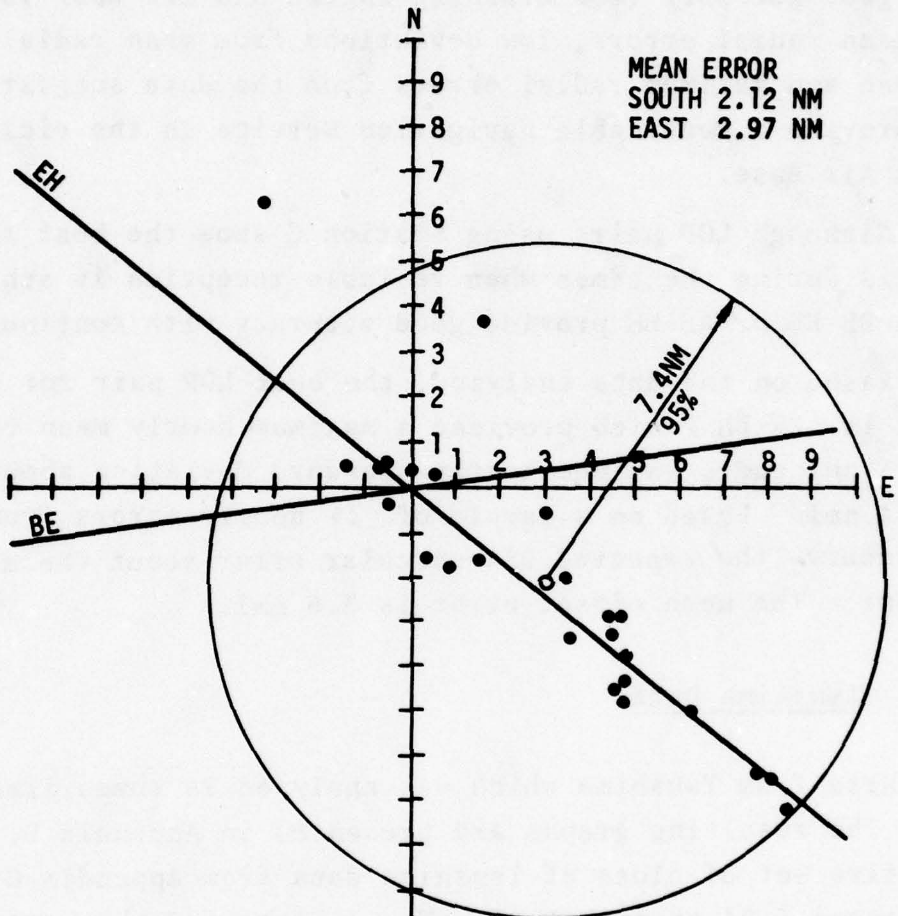

Figure 5.23 Scatter Diagram of Position Errors Observed, Clark, BE-EH, 10.2 kHz, 1/77

confirmed by the measured data. Station C provided good signals during the daytime.

The Clark error summary provided in Table 5.7 also shows a distinct relationship between error values and geometry. LOP pairs with good geometry (LOP crossing angles and low GDOP values) gave low mean radial errors, low deviations from mean radial error values of mean and maximum radial errors from the data suggest that Omega can provide a reasonable navigation service in the vicinity of Clark Air Base.

Although LOP pairs using Station C show the best statistics, this is during the times when reliable reception is achieved. LOP pairs BE-EH or AE-EH provide good accuracy with continuous coverage.

Based on the data analyzed, the best LOP pair for use at Clark is BE-BH which provided a maximum hourly mean radial error of 6.3 nmi and a maximum hourly standard deviation about the mean of 3.4 nmi. Based on a sample of 24 hourly errors from the month of January, the expected 95% circular error about the mean is 7.4 nmi. The mean offset error is 3.6 nmi.

5.3.5 Tsushima Data

Data from Tsushima which was analyzed is summarized in Table 5.8. The resulting graphs are presented in Appendix D. A representative set of plots of Tsushima data from Appendix C is shown in Figures 5.24 through 5.27. These plots and the scatter diagram of the Tsushima data (Figure 5.28).and the summary of Tsushima data follow the sequence of definitions described in Section 5.3.2 for Kwajalein data except that the plots of measured phase have not been provided. LOP pairs AC and DE for July 1976 are used in the examples shown.

Comments on Tsushima Data:

The data show that signals are reliably received at Tsushima from Omega transmitting stations A, C, D, and E. Signals from the Tsushima transmitting station H are also received for monitoring.

Table 5.8
Tsushima Processed Data

TYPE OF PLOT	FREQUENCY (kHz)	STATIONS
PHASE DIFFERENCE ERROR JULY 1976 POSITION FIX ERROR JULY 1976	10.2	AC, AD, AE, CE & DE AC-CE, AC-DE, AD-AE, AD-DE, AC-AE
PHASE DIFFERENCE ERROR JULY 1976 POSITION FIX ERROR JULY 1976	13.6	AC, AD, AE, CE & DE AC-AE, AC-CE, AC-DE, AD-AE, AD-DE

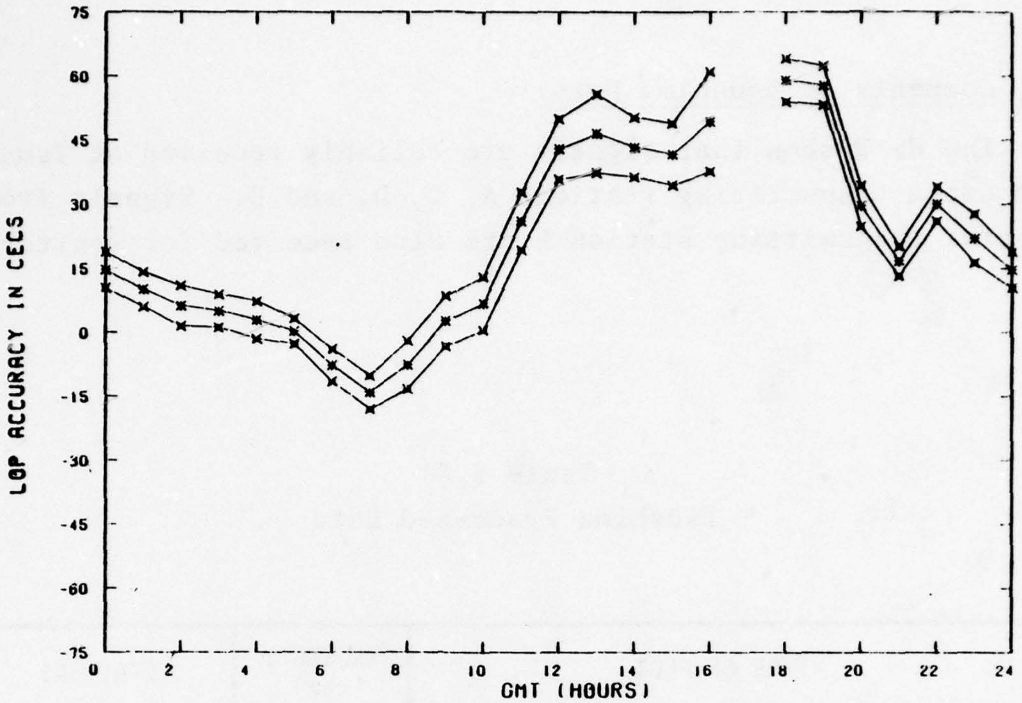

Figure 5.24 Phase Difference Error, Tsushima, AC, 10.2, 7/76

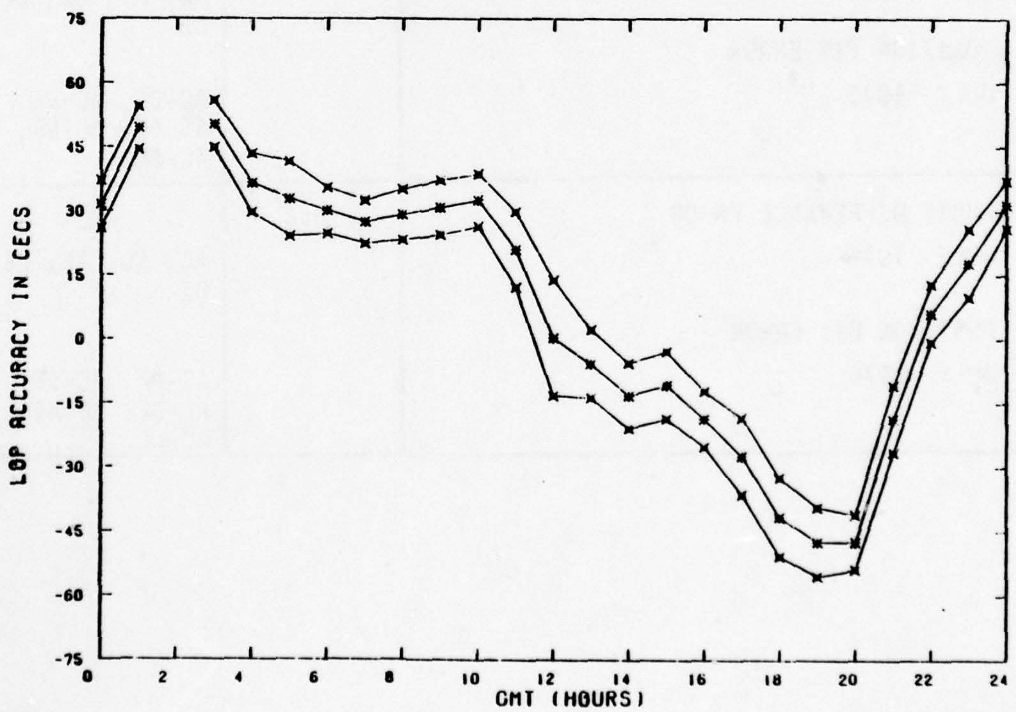

Figure 5.25 Phase Difference Error, Tsushima, DE, 10.2, 7/76

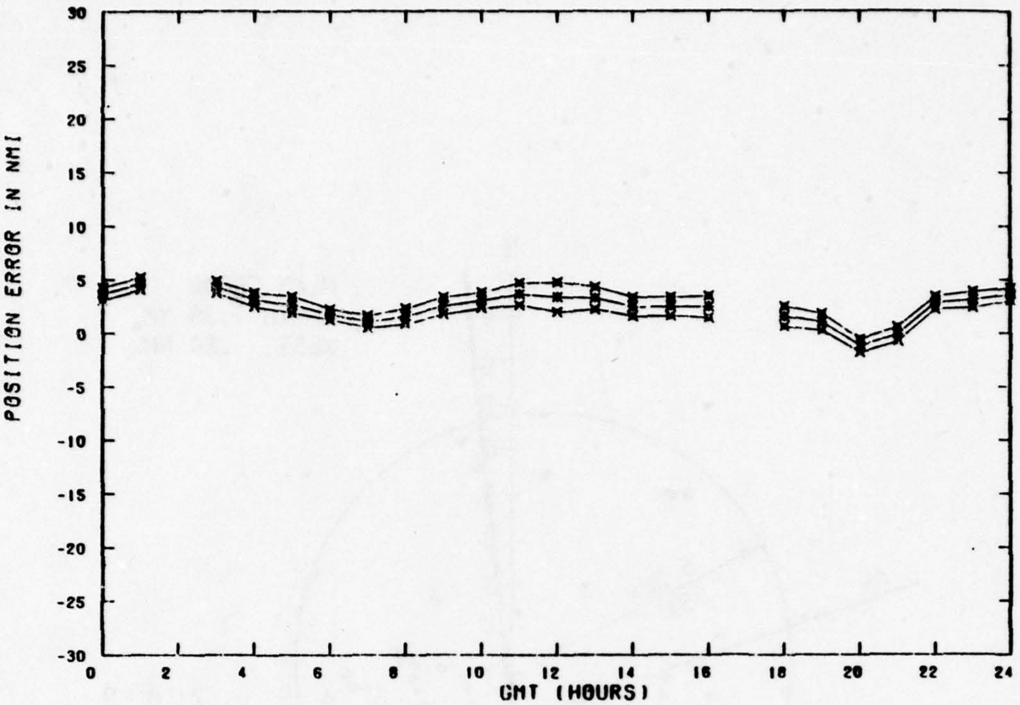

Figure 5.26 East Position Error, Tsushima, AC-DE, 10.2, 7/76

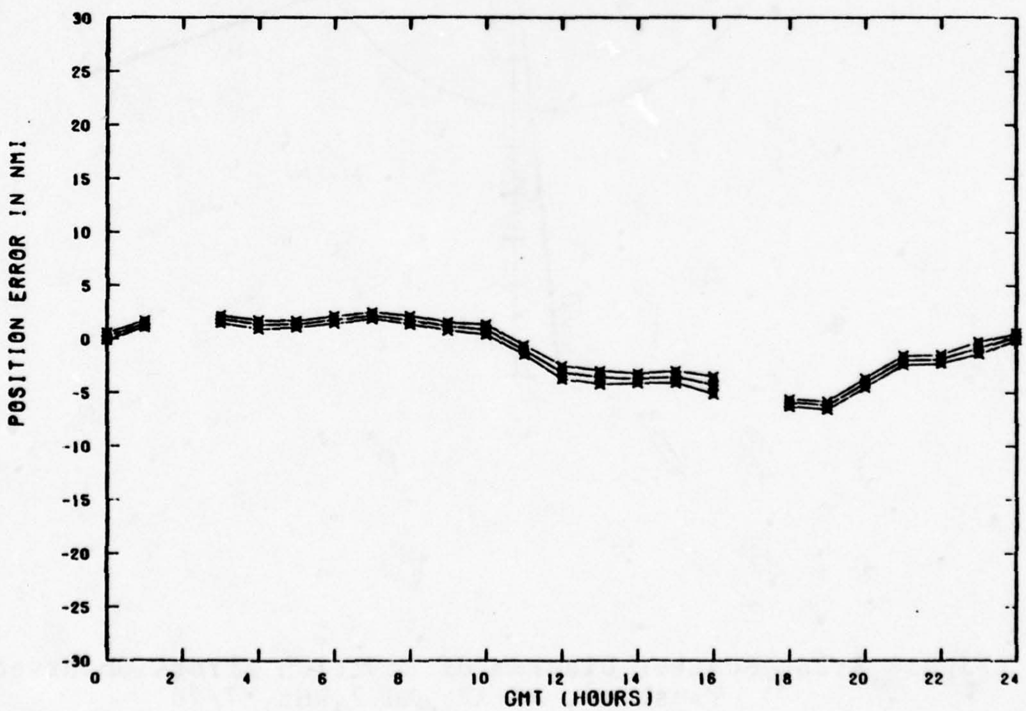

Figure 5.27 North Position Error, Tsushima, AC-DE, 10.2, 7/76

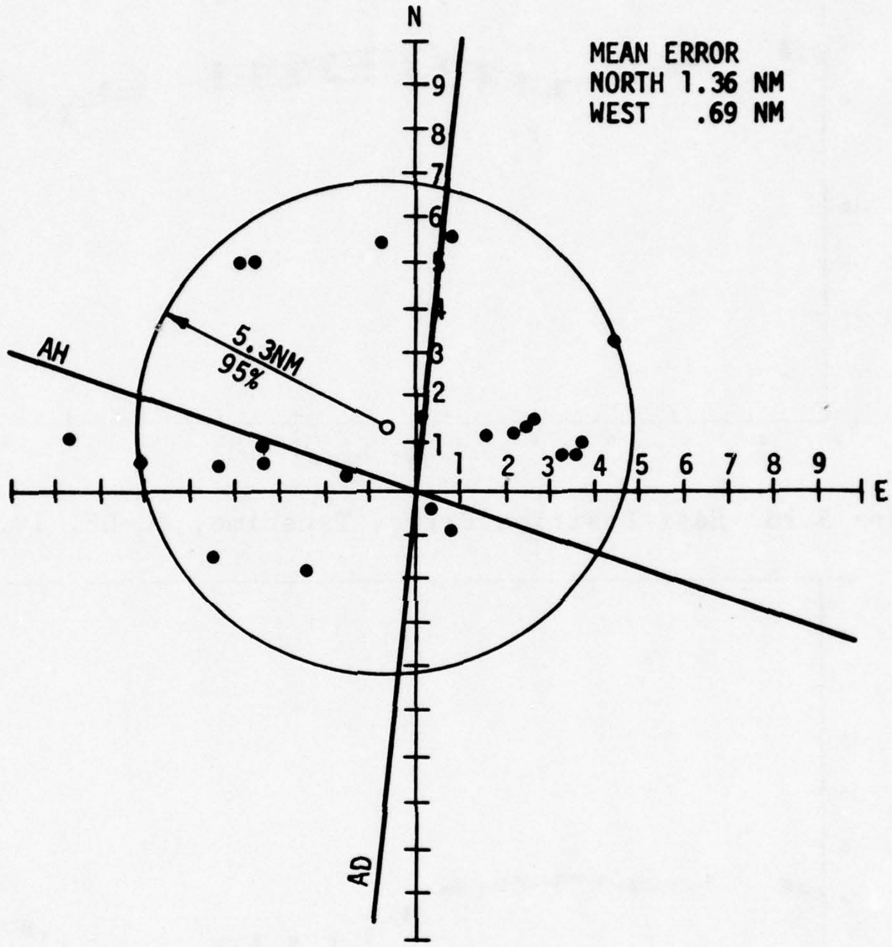

Figure 5.28 Scatter Diagram of Position Errors Observed, Tsushima, AD-AE, 10.2 kHz, 7/76

Table 5.9

Error Summary of Tsushima LOP Data, 10.2 kHz

LOP PAIR	DATE MONTH/YEAR	LOP CROSSING ANGLE	GDOP	MAX RADIAL ERROR			MAX STANDARD DEVIATION		MEAN RADIAL ERROR N.M.	MEAN STANDARD DEVIATION N.M.
				N.M.	DIREC-TION	HOUR GMT	N.M.	HOUR GMT		
AC-DE	7/76	71.7°	1.22	6.3	279°	19	1.5	12	3.8	.9
AC-CE	7/76	46.7°	1.29	6.2	283°	18	1.2	16	3.7	.8
AC-AE	7/76	81.6°	1.29	6.2	283°	18	1.2	16	3.6	.8
AD-AE	7/76	73.4°	2.05	6.7	281°	19	2.4	12	3.6	1.3
AD-DE	7/76	46.7°	2.05	6.7	282°	19	2.4	12	3.6	1.3

The Tsushima error summary provided in Table 5.9 also shows a relationship between error values and geometry. Minor variations in this relationship can be seen in the table where the LOP pair with the best geometry, AC-DE, produced slightly larger mean and maximum errors than other pairs with slightly less favorable geometry. All error values tabulated from the LOP pairs shown in Table 5.9 resulted in acceptable Omega service for the area near Tsushima, Japan.

Based on the data analyzed, the best LOP pair for use at Tsushima is AD-AE which provided a maximum hourly mean radial error of 6.7 nmi and a maximum hourly standard deviation about the mean of 2.4 nmi. Based on a sample of 24 hourly errors from the month of July, the expected 95% circular error about the mean is 5.3 nmi. The mean offset error is 1.8 nmi.

If the sample points are analyzed separately for local daytime and local nighttime the 95% circular error about the mean is 5.0 nmi for daytime and 4.5 nmi for nighttime.

5.3.6 Darwin Data

Only limited data were available from the ONSOD Omega monitoring site at Darwin, Australia at the time of preparation of this report. Because of the limited data only the LOP Phase Difference Error plots were generated. Plots for LOPs AB, AE, BH, and EH for data accumulated during August, September and October 1977 are shown in Figures 5.29 through 5.32. Data in these plots show expected and reasonable diurnal variations which suggest the normal reception of Omega transmitting stations A, B, E, and H at Darwin.

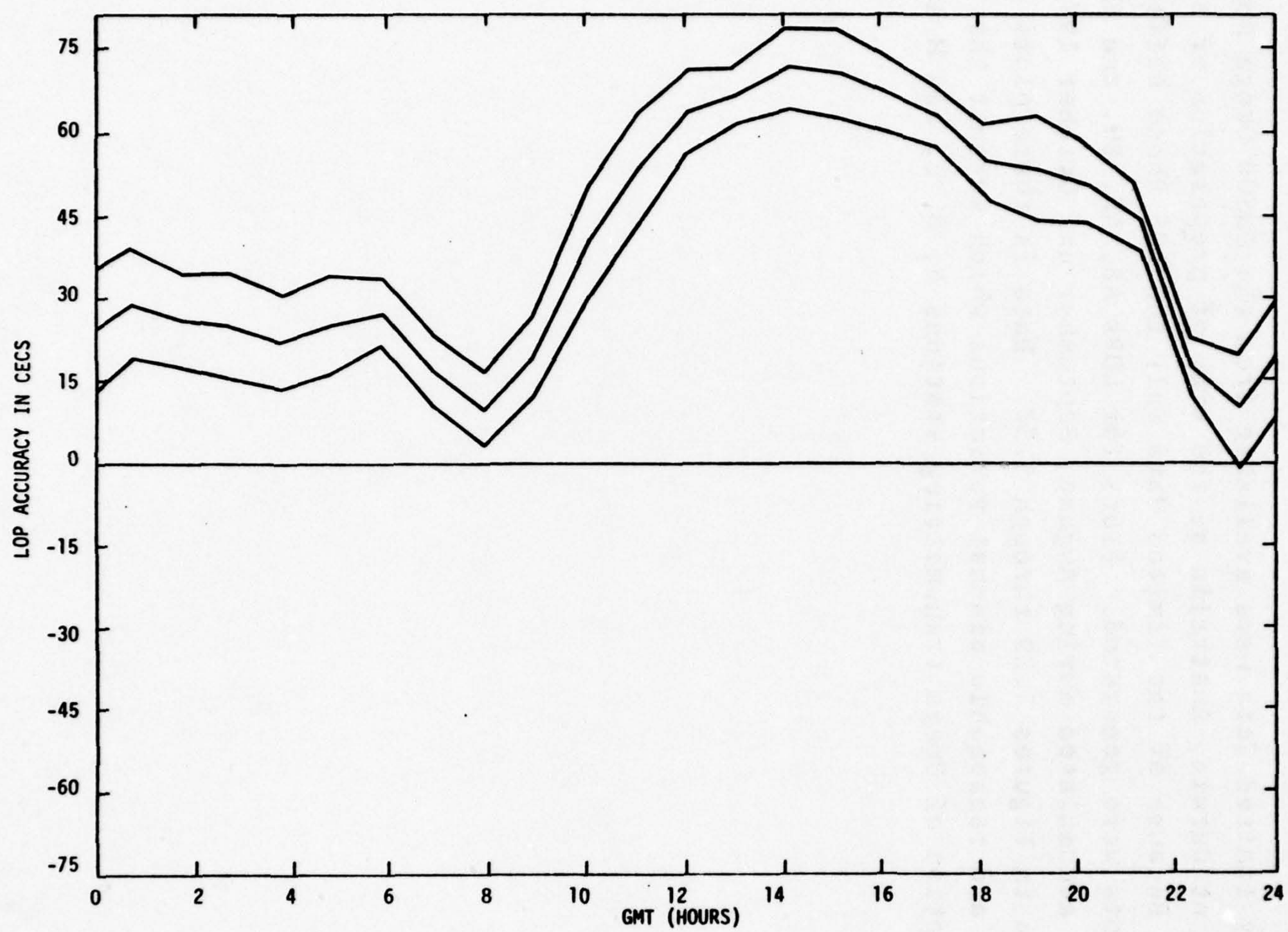

Figure 5.29 Phase Difference Error, Darwin, AB, 10.2, August, September, October 1977

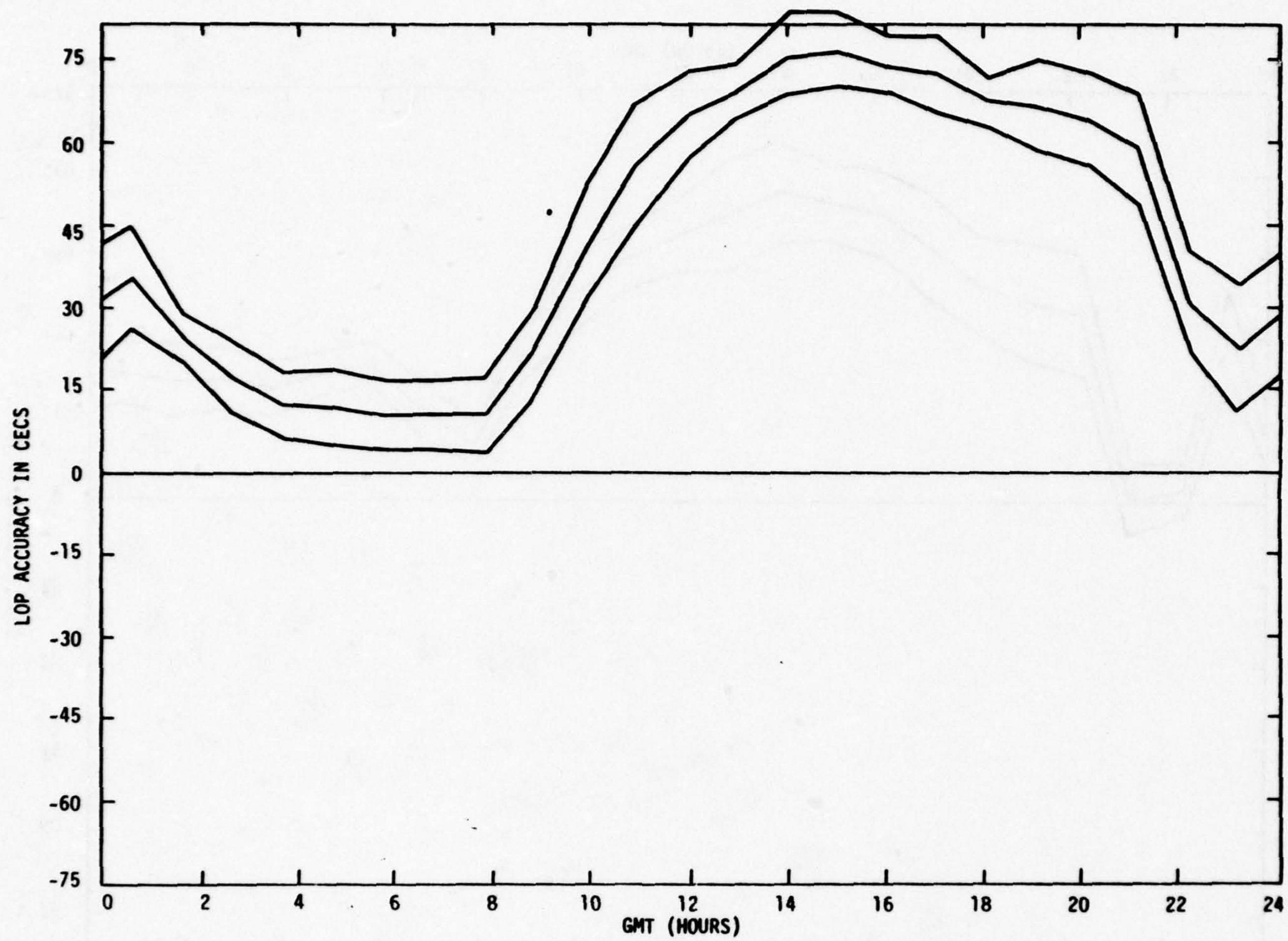

Figure 5.30 Phase Difference Error, Darwin, AE, 10.2, August, September, October 1977

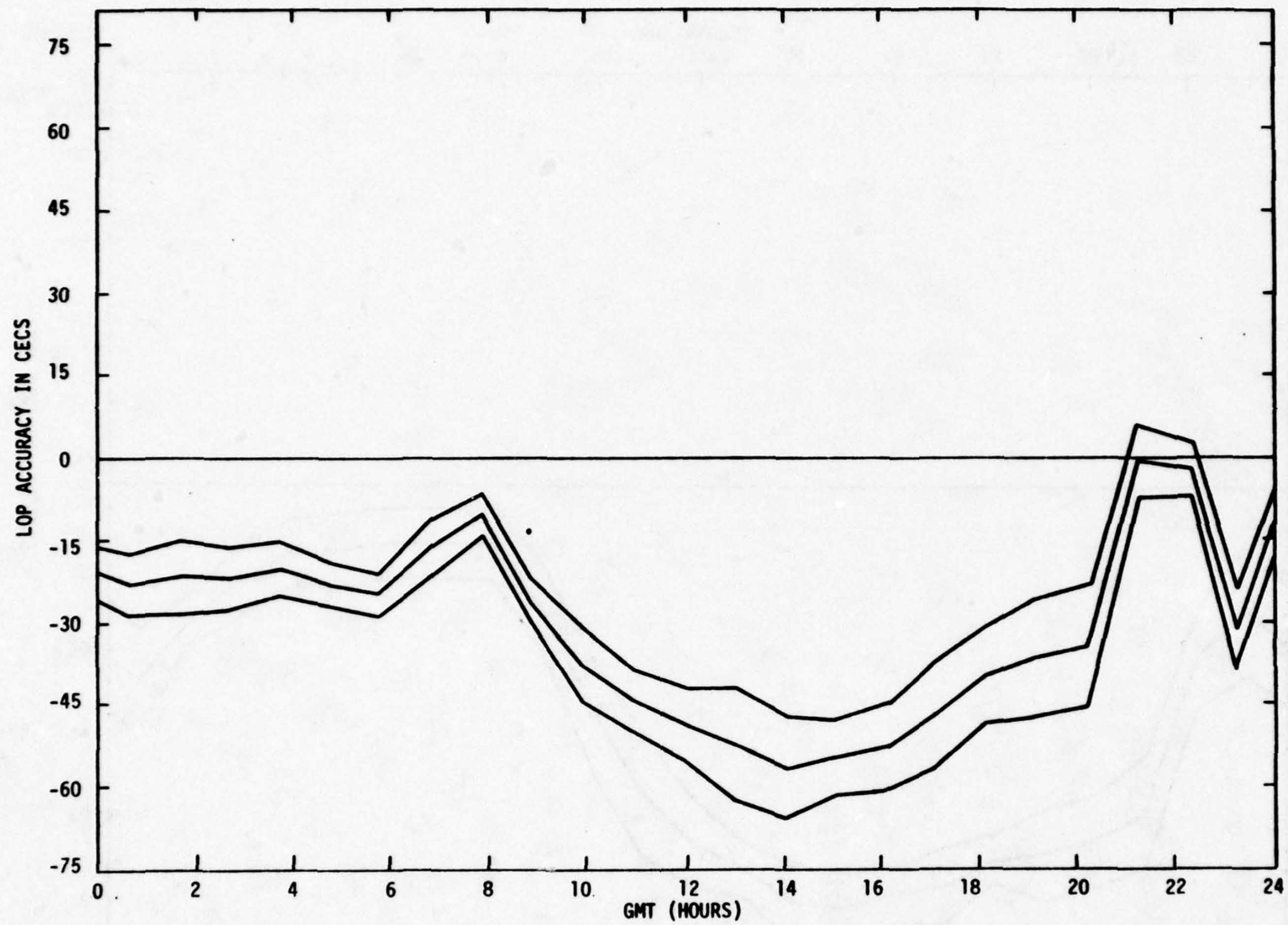

Figure 5.31 Phase Difference Error, Darwin, BH, 10.2, August, September, October 1977

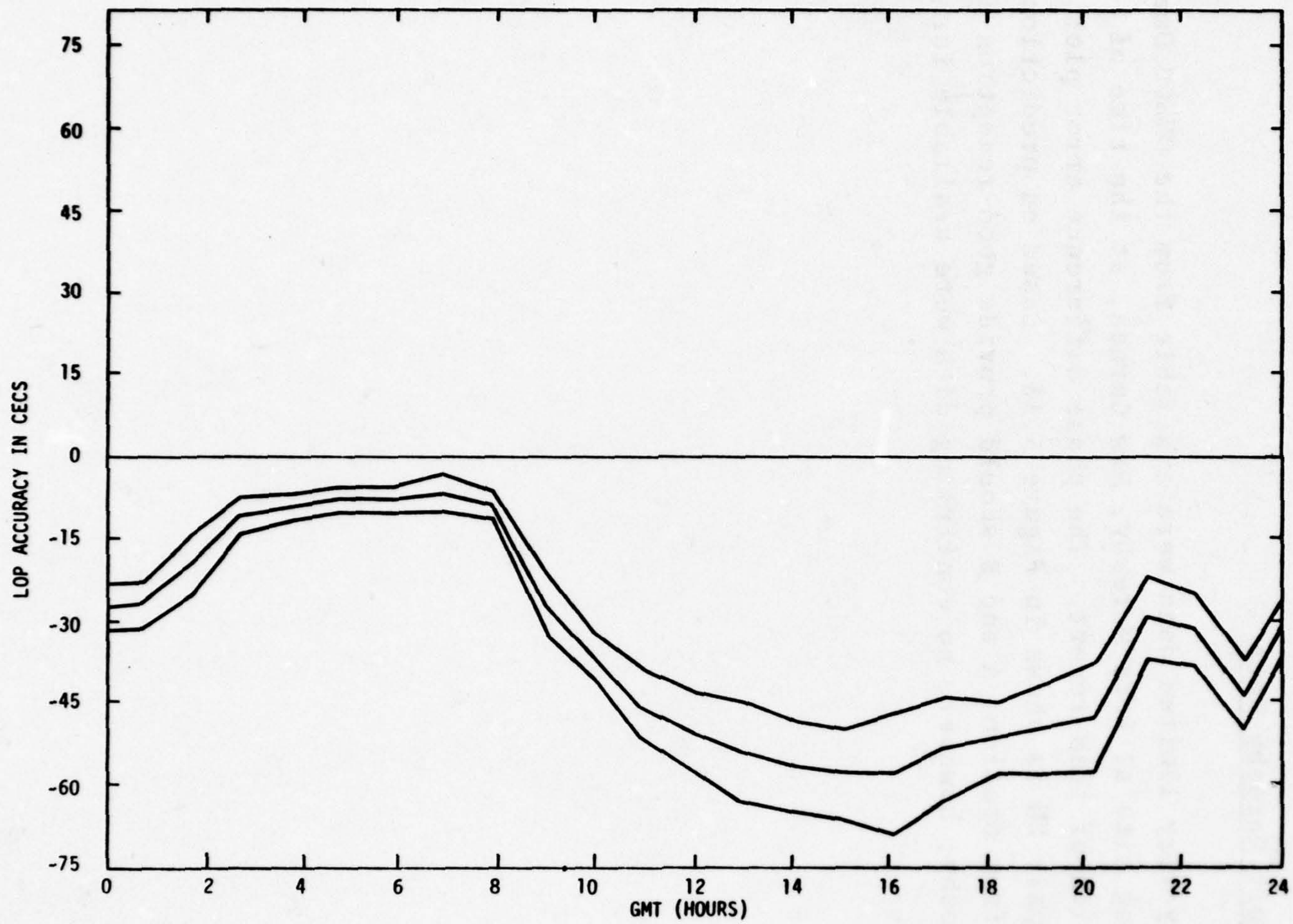

Figure 5.32 Phase Difference Error, Darwin, EH, 10.2, August, September, October 1977

5.3.7 Port Moresby Data

Only very limited data were available from the ONSOD Omega monitoring site at Port Moresby, New Guinea, at the time of preparation of this report. The phase difference error plot for the LOP pair EH is shown in Figure 5.33. Based on predictions, signals from Stations A and B should provide good reception at Port Moresby; however, no confirming data were available for analysis.

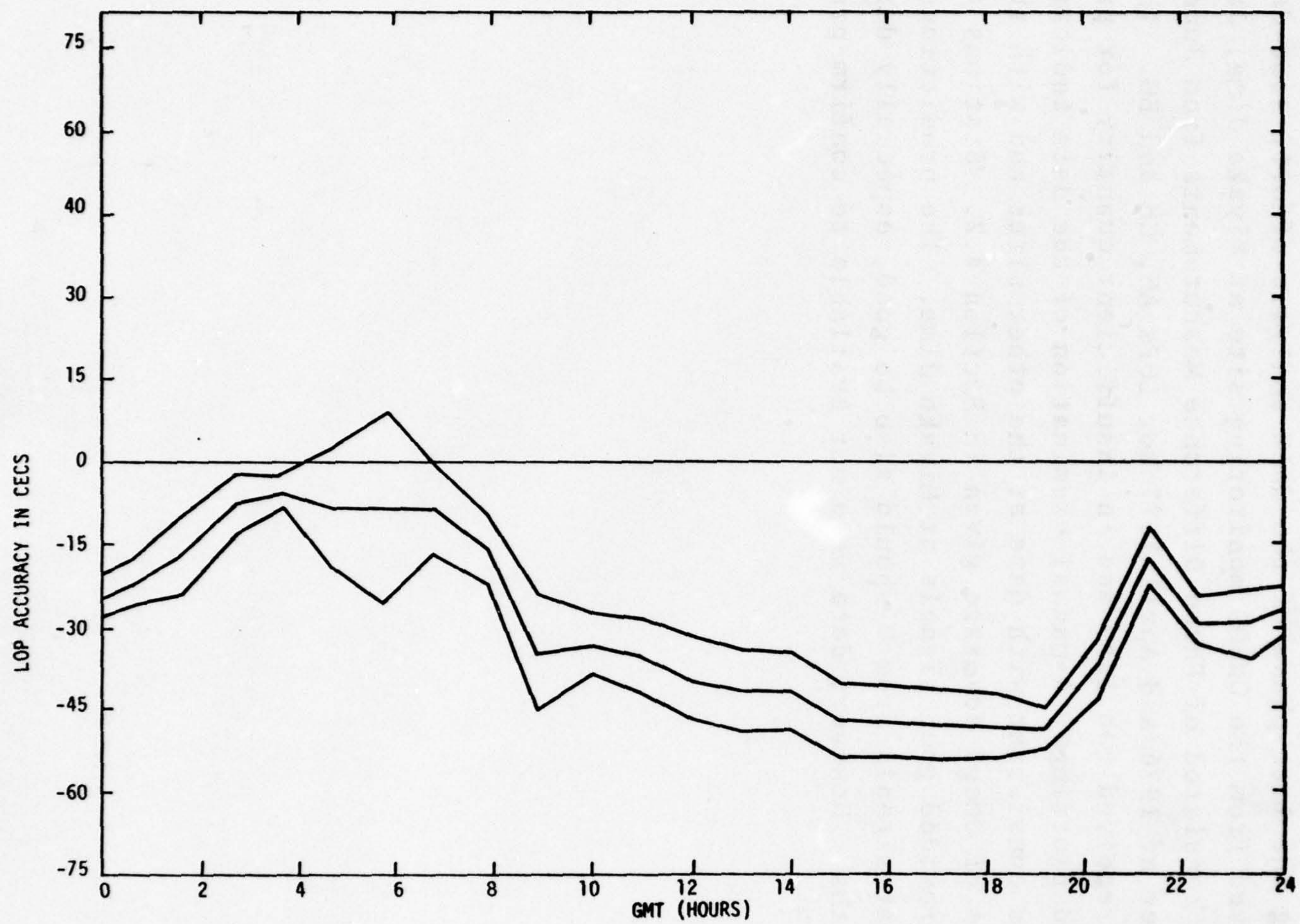

Figure 5.33 Phase Difference Error, Port Moresby, EH, 10.2, August, September, October 1977

5.3.8 Miyako Jima Data

During the late phase of the data analysis effort, some data were received from the ONSOD monitoring site at Miyako Jima, Japan. These data consisted of Phase Difference Measurements from June to September of 1976 and April 1977 for LOPs AH, CH and EH. The data were received too late and in insufficient quantity for processing and plotting. A manual examination of the data indicated that it was consistent with data at the other sites and with the predictions of Omega coverage given in Section 4.2. Stations A, C, and E provided good signals at Miyako Jima. The predictions suggest that signals from D should also be good, especially during winter months. However, data were not available to confirm predictions.

5.4 NOSC AIRCRAFT AND TEMPORARY SITE DATA

The NOSC aircraft measurements and temporary fixed site measurements were conducted late in 1977, and NOSC personnel had not completed their data analysis at the date of this report. NOSC draft reports and NOSC raw data which were in a suitable format were reviewed.[16] Some NOSC data (1) were combined with predicted noise levels (2) and compared with S/N threshold predictions (3).

Table 5.10 summarizes available data for 10.2 kHz from NOSC primary site at Clark AB, Orote Point, Port Moresby, and Darwin. Predicted and measured S/N values are shown. Table 5.11 summarizes available data for 13.6 kHz for the same sites (predictions were not available for 13.6 kHz). Measured signal strengths from Liberia were found to be 7 to 18 db higher than predicted by the NOSC equivalent mode model. Measured signal strengths from Hawaii were 5 to 10 db lower than predicted. Measured signal strength from other stations were generally less than 6 db from their predicted values.

It is of interest to note that the Tracor Omega navigation system used Station H for navigation for the entire Japan to Jakarta flight, except while near Station H, because of its internal range limit, and just prior to touchdown at Jakarta where the signal quality dropped off. The signal quality, related to S/N, showed relatively high readings except for about a half-hour period which occurred near a predicted modal interference signal null near 4 Mm from Japan.

Unpublished NOSC data were also reviewed for general consistency with the ONSOD data and with the experience of initial Omega users in the Western Pacific. No significant discrepancies were found with either ONSOD or user data in this preliminary and limited examination and general agreement was noted.

Table 5.10
Signal-to-Noise Ratio Comparison at 10.2 kHz
(100 Hz BW)

MONITOR SITE	OMEGA STATION	SIGNAL-TO-NOISE RATIOS (SUMMER) db			
		PREDICTED *		OBSERVED **	
		MIDDAY 0300 GMT	MIDNIGHT 1500 GMT	MIDDAY 0300 GMT	MIDNIGHT 1500 GMT
CLARK AB, PHILIPPINES	NORWAY	-25	-23	-26	-21
	LIBERIA	-31	-31	-23	-18
	LA REUNION	-10	+2	-5	-4
	JAPAN	+10	+5	+7	0
OROTE POINT, GUAM	LIBERIA	-36	-38	-28	-24
	HAWAII	-5	-7	-10	-12
	LA REUNION	-14	+3	-8	-2
	JAPAN	+11	+5	+14	+9
PORT MORESBY	LIBERIA	-20	-22	-13	-6
	HAWAII	0	-5	-7	-9
	LA REUNION	-4	+4	+1	+9
	JAPAN	+9	+1	+12	+1
DARWIN	LIBERIA	-17	-19	-2	-1
	HAWAII	-7	-10	-17	-18
	LA REUNION	+2	+8	+6	+12
	JAPAN	+7	+2	+9	-3

*Predicted Signal-to-Noise Ratio: Signal strength from ESM Program developed by NOSC. Noise strength from CCIR Document 322.

**Observed Signal-to-Noise Ratio: Signal Strength from "Western Pacific Omega Validation Preliminary Report," NOSC, 23 November 1977. Noise from CCIR Document 322.

Table 5.11
Signal-to-Noise Ratio Comparison at 13.6 kHz
(100 Hz BW)

MONITOR SITE	OMEGA STATION	SIGNAL-TO-NOISE RATIO (SUMMER) db			
		PREDICTED *		OBSERVED **	
		MIDDAY 0300 GMT	MIDNIGHT 1500 GMT	MIDDAY 0300 GMT	MIDNIGHT 1500 GMT
CLARK AB, PHILIPPINES	NORWAY	Predictions for 10.2 kHz only.		-26	-23
	LIBERIA			-22	-23
	LA REUNION			-7	-7
	JAPAN			+6	+1
OROTE POINT, GUAM	LIBERIA			-22	-20
	HAWAII			-6	-15
	LA REUNION			-3	-1
	JAPAN			+12	+10
PORT MORESBY	LIBERIA	Predictions for 10.2 kHz only.		-7	-6
	HAWAII			-9	-12
	LA REUNION			-2	+1
	JAPAN			+13	+5
DARWIN	LIBERIA			0	+1
	HAWAII			-24	-25
	LA REUNION			+6	
	JAPAN			+11	-3

*Predicted Signal-to-Noise Ratio: Signal strength from ESM Program developed by NOSC. Noise strength from CCIR Document 322.

**Observed Signal to Noise Ratio: Signal strength from "Western Pacific Omega Validation Preliminary Report," NOSC, 23 November 1977. Noise from CCIR Document 322.

5.5 OPERATIONAL DATA

The operational records analyzed include aircraft data from Pan American World Airways and shipboard data from U.S. Navy, USCG, and maritime vessels. The views expressed by personnel evaluating Omega in operation and the data collected by those personnel appear to validate Omega performance as indicated by the predictions. The few discrepancies noted in logs can be attributed to operational problems.

More specifically, the Omega stations used operationally over the various regions of the Western Pacific are those for which coverage is indicated by the predictions. The areas of marginal coverage and suboptimal geometries for position fixing were also observed in the operational evaluations. The operational data did not reveal any significant differences with predicted coverage or accuracy.

5.5.1 Pan American World Airways

The following summaries were excerpted from the Pan American Omega evaluation reports and data logs.[8] The avionics Omega receiver was a Canadian Marconi 740. Tabulated under each flight listed below are the stations used, the S/N range (db in 50 Hz BW) as determined by the Omega receiver, and the portion of the route where each station was used by the receiver.

- Guam to Tokyo Flight 802, 17 May 1976, 0600 hours to 0900 hours GMT combined with the data from the return flight;

- Tokyo to Guam Flight 803, 17 May 1976, 1000 hours to 1300 hours GMT.

STATIONS USED	S/N RANGE db	ROUTE SEGMENT
A	-5 to -12	Entire
B	-12 to -20	Near Tokyo
C	+5 to -15	Entire
D	-8 to -13	Entire
E	+5 to -3	Entire
H	+15 Plus	Entire

- Tokyo to Hong Kong Flight 003, 18 May 1976, 0200 hours to 0545 hours GMT.

STATIONS USED	S/N RANGE db	ROUTE SEGMENT
A	-8 to -20	Entire
B	-5 to -20	Entire
C	+5 to -15	Entire
D	-10 to -20	All, except near Hong Kong
E	+8 to +2	Entire
H	+15 Plus	Entire

• Hong Kong to Sydney via Jakarta Flight 812, 19 May 1976, 1115 hours to 2220 hours GMT.

STATIONS USED	S/N RANGE db	ROUTE SEGMENT
A	-8 to -20	Intermittent
B	+5 to -15	Entire
C	-5 to -15	Intermittent
E	+10 to 0	Entire
F	-5 to -15	Near Sydney
H	+5 to -10	Entire

• Adelaide, Australia to Singapore, Flight E901, 19-20 September 1977, 2150 hours to 0620 hours GMT.

This flight transited the southwestern corner of the Western Pacific area under consideration. During the course of the flight, the Omega position was compared to VOR locations on two occasions. Data available was analyzed and is summarized below:

Port Hedland, Australia VOR, 20°23'S/118°37'E
Omega Position Offset - 1 nm N and 0.5 nm W

STATIONS USED	S/N db in 50 Hz BW	
	10.2 kHz	13.6 kHz
A	-12	-20
B	+ 3	+ 4
C	-13	- 5
E	+10	+10
H	+ 6	+10

Djakarta, Halim VOR, 6°16'S/106°53'E, 0450 GMT Omega Position Offset - 30.9 nm N and 4.6 nm W

STATIONS USED	S/N db in 50 Hz BW	
	10.2 kHz	13.6 kHz
A	-20	-10
B	- 2	- 6
C	--	-20
E	+ 7	- 2
H	- 2	- 3

The Omega set was updated to the VOR position. This was the first update since leaving Adelaide and the set tracked well for the rest of the flight into Singapore. At touchdown in Singapore, the Omega position offset was 0.3 nm S and 0.1 nm W.

- Singapore, Flight E900, 22-23 September 1977, 0500 hours to 0400 hours GMT

  The departure of the flight was delayed for one day. During this time, 13 S/N readings were made and recorded. The readings were taken between 0000 GMT and 0400 GMT. Means and standard deviations for the readings at each frequency for stations A, B, C, E, and H are shown in the table below. Relatively high S/Ns were also recorded for station G, Trinidad, but the receiver was not using G for positioning because of its internal range constraint.

	STATIONS									
	A		B		C		E		H	
FREQ.	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
10.2	-8.2	5.2	5.3	1.3	-18.7	2.4	7.3	1.3	5.2	3.3
11.3	-7.8	4.7	4.9	4.3	-14.3	4.1	8.2	1.2	6.8	4.1
13.6	-4.1	3.8	5.3	3.3	-10.6	4.1	7.7	1.0	9.4	1.7

Signal-to-Noise Ratio Means and Standard Deviations
13 data points as observed in 50 Hz BW
Singapore 3°7'N/101°32'E, 0005 GMT, 22 September 1977
to 0400 GMT, 23 September 1977

5.5.2 U.S. Navy Ships

In response to the request from the Commander of Naval Electronic Systems Command to the Commander in Chief, Pacific Fleet for operational data and experience on Omega in the Western Pacific area, data from five ships was made available and reviewed.[17]

On all ships, the receiver used was the SRN-12 which uses the 10.2 kHz frequency only. The receiver tracks up to four stations, manually selected, and records the phase difference of up to three LOPs on strip chart recorders.

- USS RANGER CV-61

  The USS RANGER CV-61 while cruising in the Western Pacific during 24-29 August 1976, compared Omega position fixes with other on-board navigation systems which included SINS updated by satellite every two hours. The only Omega stations used were C, D, and H.[18]

  "The reliability of the Omega navigation system varied from area to area. During the transit to Subic Bay, Omega fixes ranged from 1 to 15 nm from the determined position. In the Philippines area differences of up to 25 nm between the Omega positions and the determined positions were observed. The difference also varied radically from fix to fix. Lanes had to be continually reset. These conditions persisted in the South China Sea. In the Indian Ocean, the Omega fixes were very reliable and consistently ranged from on-track to 5 nm difference (average deviation from track was 2 nm)." [18]

  Table 5.12 is from the USS RANGER's position log between 24-29 August 1976 which lists the Ship's Inertial Navigation System (SINS) positions along with the Omega positions. The difference between the fixes is nautical miles is also listed.

  Near the Philippines the recommended LOPs are BE and BH. The USS RANGER used neither Station B nor E. Omega navigation chart No. 7525 for the area does not contain LOPs using Stations B or H.

- USS BROOKE FFG-1

  The USS BROOKE (FFG-1) recorded observed Omega performance during 25 April 1977 to 3 May 1977 while cruising in the South China Sea and the Gulf of Thailand.[19]

Table 5.12

Position Log - USS Ranger[18]

DATE	OMEGA POSITION	SINS POSITION	DIFFERENCE IN NAUTICAL MILES
8/23/77	15°-56.9'N 149°-52.5'E	15°-56.6'N 149°-52.7'E	0.59
	16°-14.2'N 150°-35.8'E	16°-18.9'N 150°-37.9'E	5.57
	16°-34.3'N 151°-14.0'E	16°-34.3'N 151°-10.8'E	2.56
	16°-39.0'N 151°-27.0'E	16°-42.1'N 151°-26.9'E	3.20
	16°-55.4'N 151°-45.3'E	16°-48.6N 151°-42.3'E	7.26
	17°-03.0'N 152°-17.5'E	17°-03.4'N 162°-20.0'E	2.18
	17°-27.8'N 153°-11.8'E	17°-24.7'N 153°-09.3'E	4.16
8/24/77	17°-57.0'N 154°-34.0'E	18°-01.6'N 154°-34.9'E	5.20
	18°-07.0'N 154°-50.0'E	18°-08.7'N 154°-52.4'E	3.33
	18°-15.6'N 155°-10.5'E	18°-15.6'N 155°-10.5'E	0.00
	18°-23.0'N 155°-29.4'E	18°-21.9'N 155°-28.7'E	0.69
	18°-34.5'N 155°-55.0'E	18°-27.7'N 155°-47.5'E	9.52
	18°-36.2'N 156°-04.0'E	18°-31.6'N 156°-03.9'E	4.36
	18°-57.1'N 156°-55.8'E	18°-51.2'N 156°-54.8'E	5.91
	19°-04.2'N 157°-12.4'E	18°-57.6'N 157°-12.1'E	6.35

Table 5.12 (Continued)

DATE	OMEGA POSITION	SINS POSITION	DIFFERENCE IN NAUTICAL MILES
8/24/77	19°-03.6'N 157°-29.2'E	19°-04.0'N 157°-28.7'E	0.16
	19°-11.9'N 157°-44.2'E	19°-10.5'N 157°-45.8'E	2.52
	19°-19.0'N 158°-02.0'E	19°-17.6'N 158°-03.3'E	1.73
	19°-32.0'N 158°-22.0'E	19°-24.4'N 158°-19.9'N	7.47
	19°-33.0'N 158°-36.0'E	19°-30.5'N 158°-36.7'E	2.43
	19°-37.2'N 158°-53.5'E	19°-36.2'N 158°-54.3'E	1.18
	19°-33.9'N 159°-15.9'E	19°-45.5'N 159°-19.8E	11.89
	19°-50.9'N 159°-32.2'E	19°-50.7'N 159°-36.2'E	3.78
8/25/77	20°-27.8'N 160°-20.5'E	20°-06.3'N 160°-20.9'E	21.8
	20°-03.2'N 160°-50.8'E	20°-11.8'N 160°-53.3'E	9.23
	20°-15.0'N 162°-02.5'E	20°-22.1'N 162°-02.6'E	7.17
	20°-24.0'N 162°-16.5'E	20°-25.6'N 162°-21.1'E	4.53
	20°-23.0'N 162°-39.0'E	20°-29.4'N 162°-38.2'E	6.70
	20°-33.0'N 162°-56.5'E	20°-32.9'N 162°-54.8'E	1.49
	20°-21.2'N 164°-46.2'E	20°-32.1'N 164°-50.6'E	11.68

Table 5.12 (Continued)

DATE	OMEGA POSITION	SINS POSITION	DIFFERENCE IN NAUTICAL MILES
8/25/77	20°-36.5'N 165°-11.2'E	20°-29.6'N 165°-09.7'E	6.92
	20°-48.0'N 165°-37.0'E	20°-35.6'N 165°-43.5'E	3.59
	20°-44.4'N 166°-16.8'E	20°-40.9'N 166°-17.1'E	3.17
	20°-47.8'N 166°-33.5'E	20°-42.5'N 166°-33.4'E	5.50
8/26/77	21°-01.4'N 168°-11.8'E	21°-01.4'N 168°-14.1'E	1.71
	20°-55.3'N 168°-29.2'E	21°-03.8'N 168°-29.8'E	8.88
	21°-10.4'N 168°-48.1'E	21°-08.9'N 168°-46.1'E	2.20
	21°-17.5'N 169°-04.4'E	21°-09.9'N 169°-02.3'E	7.61
	21°-09.0'N 169°-32.0'E	21°-14.4'N 169°-34.4'E	6.19
	21°-13.0'N 169°-41.0'E	21°-14.7'N 169°-46.0'E	5.14
	21°-08.8'N 170°-24.5'E	21°-18.2'N 170°-21.9'E	9.26
	21°-17.0'N 170°-33.8'E	21°-19.4'N 170°-35.2'E	2.82
	21°-24.1'N 171°-50.0'E	21°-26.3'N 171°-50.0'E	2.33
	21°-35.9'N 172°-31.2'E	21°-30.1'N 172°-30.2'E	6.40

Table 5.12 (Continued)

DATE	OMEGA POSITION	SINS OR DR POSITION	DIFFERENCE IN NAUTICAL MILES
8/26/77	21°-26.9'N 172°-49.3'E	^{DR}21°-32.6'N 172°-50.1'E	5.53
	21°-36.2'N 173°-10.2'E	^{DR}21°-34.4'N 173°-08.2'E	2.50
	21°-44.9'N 173°-31.8'E	^{DR}21°-36.1'N 173°-26.1'E	10.95
8/27/77	21°-49.0'N 175°-03.5'E	21°-49.0'N 175°-04.2'E	0.46
	21°-50.0'N 175°-23.0'E	21°-49.1'N 175°-22.1'E	1.14
	21°-57.0'N 175°-43.0'E	21°-57.7'N 175°-40.4'E	2.46
	21°-52.0'N 175°-55.4'E	21°-52.3'N 175°-59.9'E	4.51
	21°-46.9'N 176°-15.6'E	21°-56.6'N 176°-16.6'E	9.55
	21°-53.8'N 176°-34.5'E	^{DR}21°-51.9'N 176°-36.0'E	2.13
	21°-56.1'N 176°-39.5'E	^{DR}21°-51.9'N 176°-42.5'E	4.60
	21°-46.6'N 177°-09.4'E	21°-50.2'N 177°-10.2'E	3.39
	21°-45.6'N 177°-27.4'E	^{DR}21°-50.2'N 177°-28.2'E	4.38
	21°-48.5'N 177°-46.8'E	^{DR}21°-50.2'N 177°-48.1'E	1.69
	21°-40.0'N 178°-05.0'E	^{DR}21°-50.2'N 178°-07.5'E	10.66
	21°-46.0'N 178°-27.0'E	^{DR}21°-50.2'N 178°-26.5'E	4.34

Table 5.12 (Concluded)

DATE	OMEGA POSITION	SINS OR DR POSITION	DIFFERENCE IN NAUTICAL MILES
8/27/77	21°-57.0'N 178°-44.0'E	DR 21°-51.2'N 178°-45.3'E	5.38
	21°-53.0'N 179°-06.0'E	DR 21°-51.3'N 179°-04.0'E	2.39
	21°-53.0'N 179°-0.10'E	DR 21°-51.0'N 178°-59.3'E	2.44
	21°-52.0'N 179°-16.5'E	DR 21°-51.2'N 179°-13.8'E	2.41
	21°-52.4'N 179°-36.8'E	DR 21°-52.4'N 179°-35.2'E	1.86
	21°-52.4'N 179°-44.9'E	DR 21°-52.4'N 179°-44.9'E	0.00
	21°-52.4'N 179°-57.5'E	DR 21°-54.2'N 179°-54.2'E	3.65

66 Data Points

Mean = 4.7 n.m.

Standard Deviation = 3.7 n.m.

"In general, Omega navigation was found to be very good during our transit through the area. Hourly Omega fixes were taken and were generally accurate throughout the area addressed. It was our observation that Omega navigation was reliable and accurate until our passage of Northern Luzon and thence into the South China Sea. Four months of operations in the South China Sea and Gulf of Thailand have proven Omega navigation in this area to be very unreliable. In fact, only one line of position (E-H) can be obtained and even then only periodically. Loran-A, when available, has been our primary means of electronic navigation in the South China Sea."[19]

Table 5.13 is a listing of navigation positions obtained by Omega and other on-board navigation systems.

- USS DURHAM LKA-114

The USS DURHAM (LKA-114), on its last deployment to the Western Pacific, used Omega with good results except west of the 140° meridian where only Stations C and H were found to provide useful signals. It is not known why signals from Station E were not usable.[20]

"During DURHAM's last deployment to the Western Pacific, the Omega navigation system was used extensively and with good results while operating within the area bounded by 40° north - 10° south and 150° east - 180° east."[20]

"West of the 140° meridian Omega navigation was poor. Station C and Station H provided the only useful signals resulting in only one line of position. Loran-A coverage near Japan was excellent. Stations 2H6 and 2H7 provided good strong signals and were useful for accurate positioning. For accurate electronic navigation west of the 140° meridian either the Omega navigation system should be improved or suitable Loran coverage should remain."[20]

Table 5.13
Position Fixes - USS Brooke FFG-1[19]

DATE	TIME	POSITION	MEANS
25 APR	0800	25°-20.7N/178-08.3'E	Omega
	1200	25-16.8N/176-25.2'E	Celestial
	2000	25-27.0N/174-28.5'E	Omega
26 APR	0800	25-47.0N/171-16.0E	Celestial
	1200	25-36.0N/170-05.0E	Omega
	2000	25-57.5N/168-48.5E	Celestial
27 APR	0800	25-41.0N/165-11.5E	Celestial
	1200	26-07.0N/164-32.0E	Omega
	2000	25-50.6N/162-38.0E	Omega
28 APR	0800	25-41.0N/157-56.0E	Omega
	1200	25-23.0N/156-35.0E	Omega
	2000	24-56.0N/155-07.0E	Celestial
29 APR	0800	25-04.6N/151-43.1E	Celestial
	1200	24-56.5N/150-21.0E	Omega
	2000	29-11.8N/148-30.8E	Celestial
30 APR	0800	24-04.5N/145-41.2E	Omega
	1200	23-58.6N/144-20.0E	Omega
	2000	23-32.0N/141-34.2E	Omega
1 MAY	0800	22-19.5N/138-44.0E	Omega
	1200	22-17.0N/137-38.0E	Omega
	2000	22-06.5N/134-25.9E	Celestial
2 MAY	0800	21-50.9N/131-09.9E	Omega
	1200	21-28.3N/130-19.4E	Omega
	2000	20-30.N/128-47.0E	Celestial
3 MAY	0800	20-30.3N/125-01.2E	Omega
	1200	20-32.0N/123.47.3E	Omega
	2000	20-08.0N/122-08.5E	Omega

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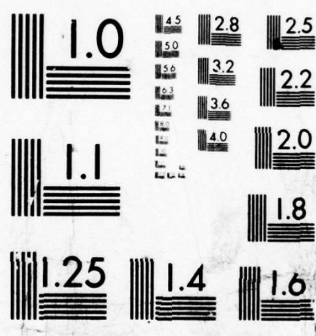


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

- USS CORAL SEA CV-43

The USS CORAL SEA (CV-43) recorded observed Omega performance for the period 15 July 1977 to 11 August 1977 while operating in the area bounded by 25 north to 35 north and 128 east to 141 east for a combined total of 20 at-sea days and 8 days anchored at Pusan, Korea. General position fix reliability and continuity was found to be excellent and dependable except for the period of time Station A was down for maintenance.

"Station A was down for maintenance until 25 July 1977, which severely limited Omega reliability southwest of Tsushima Island.

"In the East China Sea and Korea Straits area southwest of Tsushima Island, without availability of Station A, Omega reliability is drastically reduced and coverage is limited to two LOPs base line extensions for station pairs C-H and D-H, plus proximity of H transmitter preclude usage of these pairs. Chart coverage is inadequate during periods of the loss of station A. N.O. Chart 7516 presents C-D hyperbolas, but not C-E. N.O. Chart 7617 presents C-E hyperbolas, but not C-D. CORAL SEA utilized N.O. Chart 7516 by constructing C-E hyperbolas on the chart from lattice tables. After departing Pusan, Korea on 27 July 1977, using station pairs A-C, A-E, and C-E, fix reliability was excellent ranging from zero miles to 3 mile fix differences compared with visual bearings, radar and SRN-9 satellite fixes. DR fix comparison ranged from zero to 5 to 7 miles.

"Underway ops east of Okinawa and into East China Sea progressing north toward Pusan, Korea. North of latitude 33°, in Korea Straits southwest of Tsushima Island, Omega reliability was reduced to two LOPs due to non-availability of Station A and base line extension areas of station pairs C-H and D-H. Fix reliability east of Okinawa is excellent in areas encompassing 25 north to 29 north; 127 east to 131 east. Average fix comparison was 2.7 miles for 78 fixes. Comparison was with SRN-9 satellite, radar, and DR.

"Anchored Pusan, Korea. Station pairs A-C, A-E and C-E. Fix comparison averaged 1.5 miles while anchored (three fixes).

"Underway ops in Korea Straits southwest of Tsushima Island and north and northeast of Tsushima Island, bounded by 33N to 35-30N and 127E to 130-30E. Station pairs in use A-C, C-E. Average fix comparison was 2.8 miles for 182 fixes. Comparison was with SRN-9 satellite, radar, visual bearings and DR." [21]

"Underway ops in Korea Straits southwest of Tsushima Island, East China Sea and Pacific Ocean areas south of Honshu, Japan bounded by 30N to 35N; 128E to 141E. Station pairs in use A-C, A-E, C-E. Average fix comparison 4.2 miles for 96 fixes. Fixes in an area bounded by 34 north to 36 north 140 east to 143 east consistently compared from 3 to 7 miles north of ship's known position. Comparison was with SRN-9 satellite and radar. After mooring Yokosuka, Japan, Omega fix was 4 miles north of pier.

"General fix reliability and continuity are excellent and dependable showing an average comparison with SRN-9 satellite, radar and visual bearing fixes of 3.3 miles in a total of 369 fixes."[21]

The average position fix comparisons as presented in the USS CORAL SEA (CV-43) report is shown in Table 5.14.

Recommendations included in the USS CORAL SEA (CV-43) report which apply to the general operational aspects of Omega are listed below:

"(a) Omega charts be constructed with a two to five mile overlap (7500 and 7600 series)

(d) Dual coverage of 7500 and 7600 series plot sheets is excessive and entails unnecessary expense and excessive stowage space. Either series is adequate.

(e) More general sailing and coastal scale charts be overprinted with Omega lanes as has been provided in the past with Loran-A. This is a very efficient time saver, eliminates posits (may produce errors), and eliminates one extra working chart."[21]

- USS TOWERS DDG-9

The USS TOWERS (DDG-9) reported on Omega performance observed during operations in the Western Pacific from 7 March 1977 to 11 March 1977.

"TOWERS transitted the geographical area of interest (14°N-21°N, 150°E-180°E) during her return transit from WESTPAC from 7 March 1977 to 11 March 1977. From 150°E to 153°E station pairs E-H, C-H, and D-E provided the best information. From 158°E to 180°E, station pairs C-D, C-H, and D-H were used.[22]

Table 5.14

Position Fix Comparisons - USS Coral Sea CV-43[21]

DATE	AVERAGE DIFFERENCE	NO. OF FIXES	CUMULATIVE	AVERAGE DIFFERENCE	NO. OF FIXES
15 Jul	3.1 mi	10		0	0
16 Jul	2.6 mi	19		2.8 mi	29
17 Jul	2.6 mi	21		2.7 mi	50
18 Jul	3.0 mi	21		2.8 mi	71
19 Jul	2.8 mi	13		2.8 mi	84
20 Jul	3.1 mi	4		2.9 mi	80
26 Jul	1.5 mi	3	Anchored - Pusan, Korea	2.7 mi	91
27 Jul	1.5 mi	11	Underway 1030I to Pusan op area	2.5 mi	102
28 Jul	3.2 mi	22		2.6 mi	124
29 Jul	3.2 mi	23		2.8 mi	147
30 Jul	3.5 mi	22		2.8 mi	169
31 Jul	3.5 mi	24		2.8 mi	193
01 Aug	2.5 mi	24		2.8 mi	217
02 Aug	2.6 mi	24		2.8 mi	240
03 Aug	2.8 mi	24		2.8 mi	264
04 Aug	2.9 mi	9		2.9 mi	273
06 Aug	2.9 mi	11	Underway 1000I to Yokosuka, Japan	2.8 mi	284
07 Aug	3.4 mi	23	1000I-Entered Pacific Ocean 100 miles south of Yokosuka	2.8 mi	307
08 Aug	3.9 mi	15	Changed station pairs chart; power loss 090930I	3.0 mi	322
09 Aug	4.9 mi	15	Re-start 090930I	3.0 mi	337
10 Aug	5.4 mi	24		3.9 mi	361
11 Aug	3.6 mi	8		3.3 mi	369

"The Omega navigation system produced satisfactory results throughout the transit. The system required resetting twice each day after comparing with celestial fixes. Reliable information was normal during day and night operation, but strong fluctuations invariably occurred at dawn and dusk. The system usually began running out of lanes about one hour prior to sunrise and sunset, and this condition remained present until about one hour after sunrise and sunset.

"Based on TOWERS' experience operating throughout the Western Pacific Ocean, Omega is a valuable and accurate navigational tool when used in conjunction with celestial methods."[22]

5.3.3 Maritime Ship - SS Wyoming

Of the data reviewed, the most useful was that acquired during transit from Okinawa to Jakarta with intermediate stops.[13] The data acquired during this part of the cruise was analyzed and the results are summarized below. Of significant interest was the use of Station A for the entire cruise. Also Stations C and D were used for a large number of position fixes. Stations B and H provided relatively good signal-to-noise ratios throughout this portion of the cruise. Station E, which provides excellent coverage over this area, was purposely de-selected and its time slot was used for calibration purposes.

Omega position fixes were compared to satellite position fixes at 59 locations. The Omega receiver was programmed to compute a position fix based on each of the three frequencies independently. A position was computed only if the signal-to-noise ratios from three or more stations at the frequency under consideration, and geometry threshold conditions based on those stations, were met. There were numerous points where positions were achieved at only one or two frequencies. The number of position fixes achieved out of the possible 59 points are listed below for each frequency.

FREQUENCY	POSITION FIXES ACHIEVED
10.2 kHz	48
11-1/3 kHz	52
13.6 kHz	58

For each point where a position fix was achieved, one or more solution was derived based on various station and LOP combinations. For each of these solutions, the difference between the satellite fix and the Omega fix was computed in terms of range (nmi) and bearing as illustrated in Table 5.15.

Table 5.15

Satellite and Omega Position Fix Differences

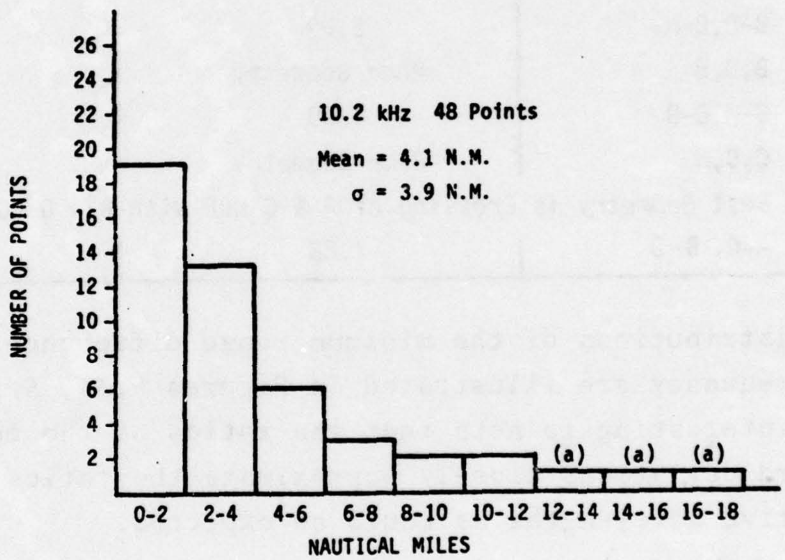
Date: 15 October 1977
Frequency: 10.2 kHz
Lat: N 25 08.55; Lon: E 121 44.82; GMT: 15 44 49

STATIONS	RANGE DIFFERENCE	BEARING OF DIFFERENCE
A,B,C	4.09	52.13
A-B,C-D	6.57	98.86
A-B,C-H	6.89	100.96
A,B,D	7.35	-9.00
A-B,D-H	Poor Geometry	
A,B,H	6.24	-1.92
A-C,B-D	1.88	126.05
A-C,B-H	1.85	119.06
A,C,D	7.89	-168.22
A-C,D-H	Poor Geometry	
A,C,H	7.46	-169.01
A-D,B-C	Poor Geometry	
A-D,B-H	9.69	-6.38
A-D,C-H	7.63	-167.87
A,D,H	Poor Geometry	

(Continued on following page)

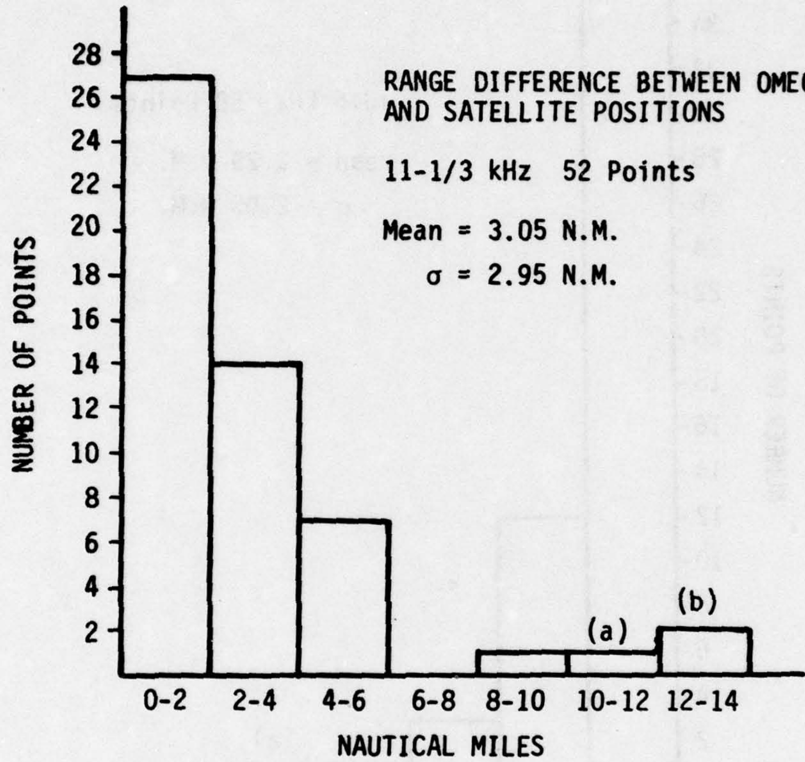
STATIONS	RANGE	BEARING
A-H,B-C	Poor Geometry	
A-H,B-D	4.75	-4.16
A-H,C-D	7.72	-169.21
B,C,D	4.98	149.41
B-C,D-H	Poor Geometry	
B,C,H	5.09	150.34
B-D,C-H	5.09	149.68
B,D,H	Poor Geometry	
B-H,C-D	4.99	150.01
C,D,H	Poor Geometry	
Best Geometry is Crossing of A & C LCP with B & D LOP		
A-C, B-D	1.88	126.05

Distributions of the minimum range differences achieved for each frequency are illustrated in Figures 5.34, 5.35, and 5.36. It is interesting to note that the ratios of the means and standard deviations closely approximate the ratios of the respective wavelengths as would be expected.



(a) Three position fixes taken at approximately 25°9'N/121°45'E on 15 October 1977 between 2145 and 2330 GMT. Only Stations A, B, and H had S/N above threshold. Station E was not used.

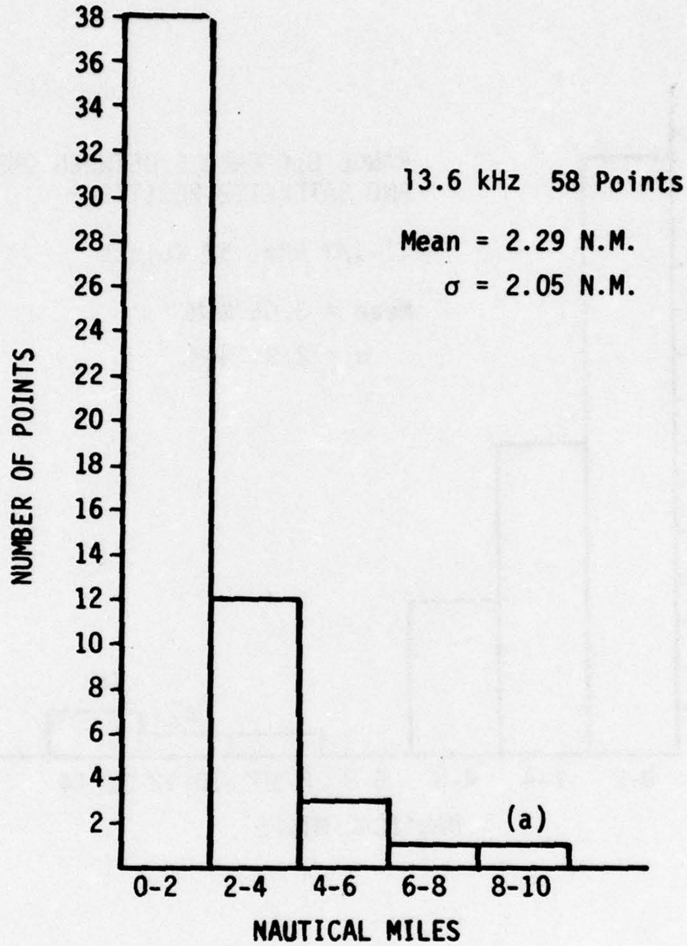
Figure 5.34 Range Difference Between Omega and Satellite Position, 10.2 kHz, 48 Points



(a) Position fix taken at approximately 4°2'N/106°5'E on 20 October 1977 at 1808 GMT. Only Stations A, B, and H had S/N above threshold.

(b) These position fixes were taken at approximately 25°9'N/121°45'E on 15 October 1977 between 2145 and 2330 GMT. Only Stations A, B, and H had S/N above threshold. Station E was not being used.

Figure 5.35 Range Difference Between Omega and Satellite Position, 11-1/3 kHz, 52 Points



(a) Position fix taken at approximately 1°15'N/103°52'E on 21 October 1977 at 1945 GMT. Stations A, B, and H were used. S/N for C and D was below threshold. Station G showed S/N above threshold, but was not used by the receiver. Station E was purposely de-selected.

Figure 5.36 Range Difference Between Omega and Satellite Positions, 13.6 kHz, 58 Points

5.6 LORAN-A EVALUATION

The Loran-A coverage charts for the Western Pacific region are shown in Figure 5.37.[23] Discontinuance of the Loran-A chains in the Western Pacific causes no significant loss of navigational signal coverage with the possible exception of the Mariana Island chain at midnight, mid-winter. Although four Omega stations, ABEH, are predicted to provide coverage at midnight, mid-winter, the LOP geometry for these stations is not favorable. However, the Australia station will alleviate this problem. Note that the region in the vicinity of the Philippines with marginal Omega coverage will continue to be supported by Loran-A.

Operational Loran-A data from Continental Airlines and the USCGC Mallow were examined. The Continental Airlines data consisted of 19 flights between Honolulu and Guam and were in the coverage region of the Mariana Island, Marshall Island, and Hawaiian Island Loran-A chains.[15] The USCGC Mallow cruised for approximately 18 days near Kwajalein and was supported by the Marshall Island chain.[11] It is of interest to note that during the 19 Continental flights, only 27 Loran-A fixes were made. Similarly, in 18 days of operation, the USCGC Mallow recorded only approximately 17 Loran-A position fixes. There undoubtedly are additional Loran-A users in this area. However, no additional operational information from these users could be located.

The only accuracy data available from operational tests have been recorded by Continental Airlines. Relative to Loran-C or Doppler, the Loran-A indicated a fix accuracy from 5 to 10 nmi.[15] This is not to be misconstrued as an absolute accuracy since Loran-C and Doppler errors are an integral part of these quantities.

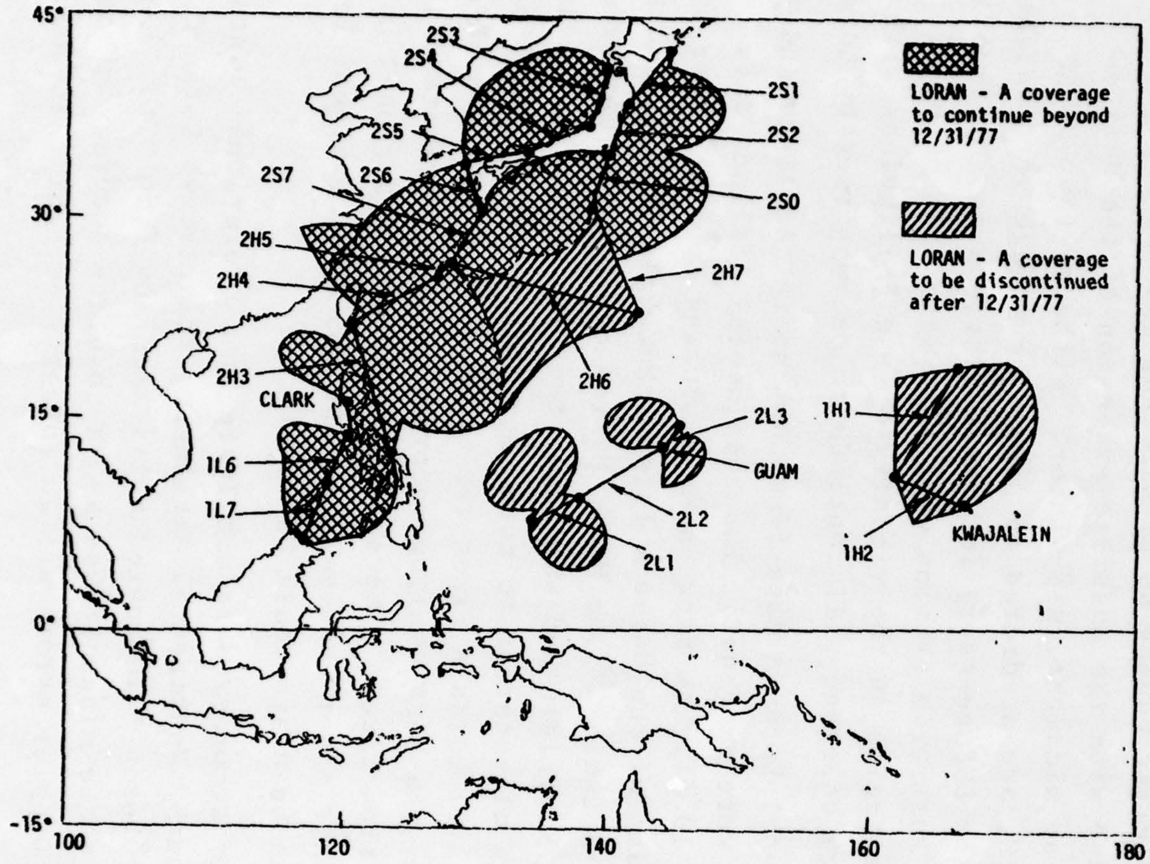


Figure 5.37 Loran-A Ground Wave Coverage, Western Pacific

5.7 ESTIMATE OF SYSTEM ACCURACY

In order to summarize the performance of the Omega system, the 95% circular error is used as a measure of accuracy. Traditionally, Omega accuracy has been quoted using values separately for day and night. This practice may not reflect the system accuracy to the navigator because:

- A large percentage of the errors are greater than the RMS value
- The day and night values are related to solar illumination of the signal propagation path. The path from the transmitter to the receiver may be partially in day and partially in night conditions. The signal characteristics will be a combination of day and night characteristics.

The measure of accuracy selected for the Omega position fix is the 95% circular error. The 95% circular error is the radius of a circle including 95% of the position fixes, both day and night. The stated accuracy goal of the Omega system is 1 nmi RMS during daytime and 2 nmi RMS at night. This can be translated to a day and night 95% circular error of 3.8 nmi, by assuming normally distributed errors in the north and east directions with equal RMS values of 1 nmi in day and 2 nmi at night, for an "average path" having one-half daytime and one-half night. The RMS error components will have a value of 1.58 nmi. For normally distributed errors with equal uncorrelated north and east errors, the distance for which a fraction, p, of the errors will be larger than, D, is given by[24]

$$D = \sigma(2 \ln \frac{1}{p})^{\frac{1}{2}}$$

For $p = 1-.95 = .05$ and $\sigma = 1.58$

$$D = 3.8 \text{ nmi.}$$

This is the stated accuracy goal for the Omega system for 95% circular error.

The relationship of the 95% circular error to the error statistics is dependent on the distribution of the errors. With the present PPCs the Omega position errors in the Western Pacific area have hourly mean values that have large values compared to the standard deviation of the daily values about the mean. As a result, most of the errors outside the 95% circle occur near the time when the hourly mean error is a maximum. The value of the 95% circular error is nearly the same as the value of the maximum hourly mean error. As an example, at Tsushima for 7/76 using recommended LOP's AD and AE, 95% of the errors are larger than 6.8 nm, the maximum hourly mean error is 6.7 nm, and the 95% value for the 23 data points of the scatter diagram is 6.6 nm. Even when the LOP's use a station suffering from modal interference, the maximum hourly mean error is representative of the 95% circular error. Using LOPs CH-EH at Orote Point for 9/77, 95% of the errors are larger than 5.8 nmi, the maximum hourly mean error is 5.4 nmi and the 95% value for the 24 data points of the scatter diagram is 5.1 nmi. The value of the maximum hourly mean error has been selected as representative of the 95% circular error at a site with present PPCs.

The hourly mean errors of the data at the ONSOD monitoring site can be used to improve the PPCs.[25] After the hourly mean errors are subtracted from the PPCs, the remaining errors will be the variation about the hourly mean values. The mean standard deviation, computed from the data at each site is a measure of the remaining variation. Assuming normal noise with equal north and east components, the 95% circular error will be 2.45 times the standard deviation of the remaining variation. Since the correction model will not be able to

fit the data at all locations, an additional .4 nmi has been included as the PPC fitting error.

The 95% circular error over the entire Western Pacific area is estimated to be 6.3 to 7.3 nmi. This estimate was obtained by dividing the area into 16 sectors. Estimated accuracy within a sector was based on the performance obtained by the monitor site most representative in geometry and signal configuration to conditions within the sector. The 95% circular error from the representative monitor site was assigned to each sector. The average of all sectors is used as the estimate for the area.

VI. OPERATIONAL CONSIDERATIONS

The data have been evaluated to identify the best usable stations and geometry over the Western Pacific area. Primary and alternate LOPs have been recommended based on operational usage in the area. Multifrequency operation provides an increase in position fixing reliability and is recommended whenever possible. Laning using 3.4 kHz appears to be unreliable until PPCs are improved for this area.

6.1 LOP SELECTION BY AREA

Under normal conditions a receiver using automatic station selection will provide continous coverage over the entire area. Coverage is provided at 10.2 kHz by at least three stations with adequate crossing angles at all times during normal system operation. Normal system operation is defined as all stations transmitting at full power (10 KW), and the absence of anomalous propagation events. At least one alternate station is available over 90% of the area during the night and 70% of the area during the day. The use of multiple frequencies may provide additional alternate stations.

For purposes of summarizing the findings in terms of recommended stations to use, the Western Pacific area has been divided into five sectors where primary LOPs have been selected. The primary LOPs can be used both day and night over 80% of the area. For the remaining 20% of the area, different LOP pairs may be required for day and night. Alternate LOPs are available over 90% of the area during the night and 70% of the area during the day.

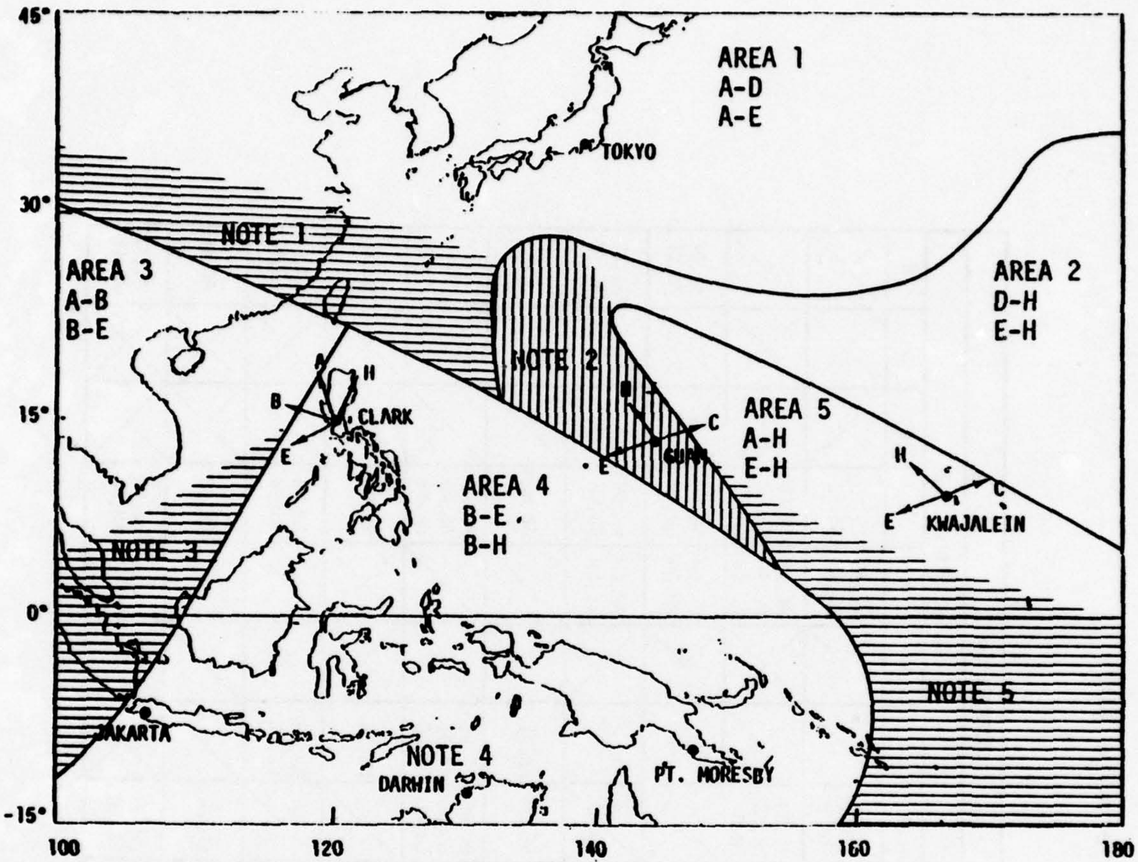
Figure 6.1 shows the division of the Western Pacific area into five areas. The LOPs selected for each area are those giving the most reliable day and night coverage in that area. Areas having cross-hatching are areas where the same three stations may not be received during both local day and night. The alternate stations, described in the notes, may have to be used during local daytime.

Alternate LOPs that are available if a station of the primary LOPs is not usable, are listed in Table 6.1. For each area, alternate stations and LOPs for day and night conditions are listed. When an alternate station is available over a portion of the area, a superscript indicates if the station is usable in the north, south, east or west sector of the area. The alternate LOP pairs are listed in the order using the alternate stations most likely to be received.

The LOPs selected for Western Pacific area were determined by finding the areas of full predicted coverage, modifying the areas using measured data, selecting common LOP areas, and selecting alternate LOPs for each area.

Starting with the predicted coverage shown in Figures 5.1 and 5.2, a composite day/night signal coverage diagram was constructed as illustrated in Figure 6.2.

Data from ONSOD monitor sites and NOSC field measurements were examined to verify the predicted coverage. The NOSC signal-to-noise data, confirmed by ONSOD data, show that the Liberia station provides longer range coverage than predicted. The ONSOD data show Norway station coverage farther south,



Note 1: H can be used as an alternate for D during local daytime in shaded area.

Note 2: C can be used as an alternate for D during local daytime in shaded area.

Note 3: H can be used as an alternate for A during local daytime in shaded area.

Note 4: Alternate stations are not required in Area 4 when the recommended stations B, E, and H are available.

Note 5: C can be used as an alternate for A during local daytime.

Figure 6.1 Recommended LOPs for Western Pacific Area Coverage Based on Use of 10.2 kHz Only and Without Station G (Australia) Coverage

Table 6.1

Alternate LOPs

AREA	PRIMARY LOPs	ALTERNATE LOPs									
		DAY OR NIGHT	ALTERNATE STATIONS	STATIONS RECEIVED							
				A	B	C	D	E	F	G	H
1	A-E	D	H,C^E	EH,DH DE,CD			AE,AC AE,AH	AD,CD AH,AE			
	A-D	N	$H^W BC^W$	BE,BD DE,CD EH,DH			AE,AB AE,AC AE,AH	AB,AD AD,CD AH,AE			
2	E-H	D	A^E,C				CH,EH AH,EH	AH,DH CD,DH			AE,DE AC,DE
	D-H	N	A,B^W				AH,EH BE,EH	AH,DH BH,DH			AE,DE AE,AB
3	B-E	D	H	BE,BH	AH,AE			AB,BH			
	A-B	N	C^N,D^N,H	BC,BE BD,BE BH,BE	AC,AE AD,AE AH,AE			AB,AC AB,AD AB,BH			
4	B-E	D	C^E		CH,EH			BH,CH			BE,BC
	B-H	N	A^W,F^E		AH,EH EF,EH			AH,BH FH,BH			AB,BE FE,BE
5	A-H	D	C	CH,EH				AH,CH			AC,AE
	E-H	N	D^N,F^S	DH,EH EF,EH				AH,DH AH,FH			AD,AE AE,EH

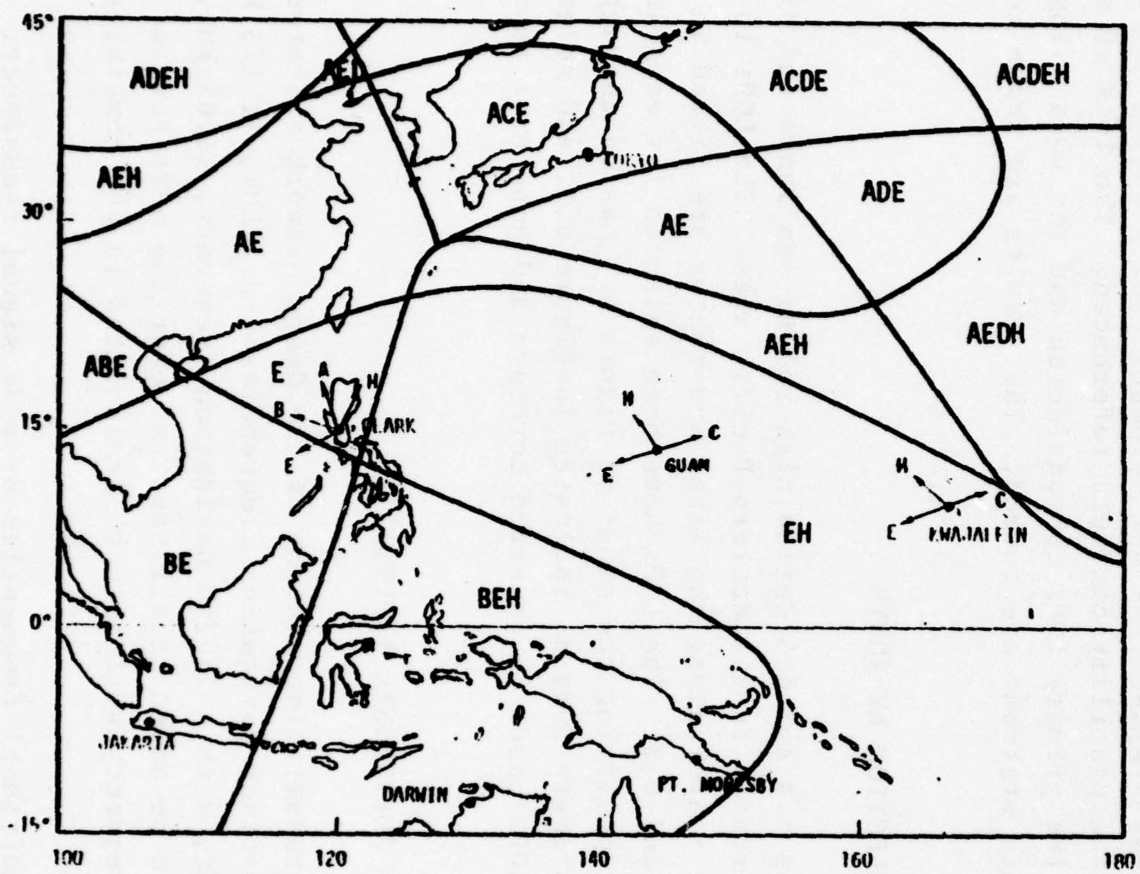


Figure 6.2. Predicted Omega Signal Usability Contours Day and Night

North Dakota station coverage farther south and Japan station coverage farther east than predicted. The expected coverage with the modifications is shown in Figure 6.3.

Alternate stations for day or night were selected for each area using the usability contours referenced. The loss of a station in the primary LOPs is considered and the LOPs using the alternate stations are formed. The results are shown in Table 6.1.

6.2 LOP SELECTION BY ROUTE

Figures 6.4 and 6.5 define high volume sea lanes and high volume air routes in the Western Pacific area. The LOPs to be used during travel along the lanes and routes are listed in Tables 6.2 and 6.3. The LOPs have been selected for each lane or route by observing the areas of Figure 6.1 passed through, selecting primary LOPs as indicated in Figure 6.1, and selecting alternate LOPs based on expected coverage and hand over to the next area.

6.3 USE OF ADDITIONAL FREQUENCIES

Each transmitting station of the Omega network radiates signals on three distinct navigation frequencies: 10.2 kHz, 11-1/3 kHz, and 13.6 kHz, with a fourth navigation frequency, 11.05 kHz, scheduled to be added to all stations over the next several years. A unique frequency will also be transmitted in the remaining four time slots.

The additional frequencies provide signal redundancy. The multiple frequency signals transmitted by the Omega network can be used to overcome the temporary loss of one frequency due to fading, or the anomalous phase behavior of one frequency.

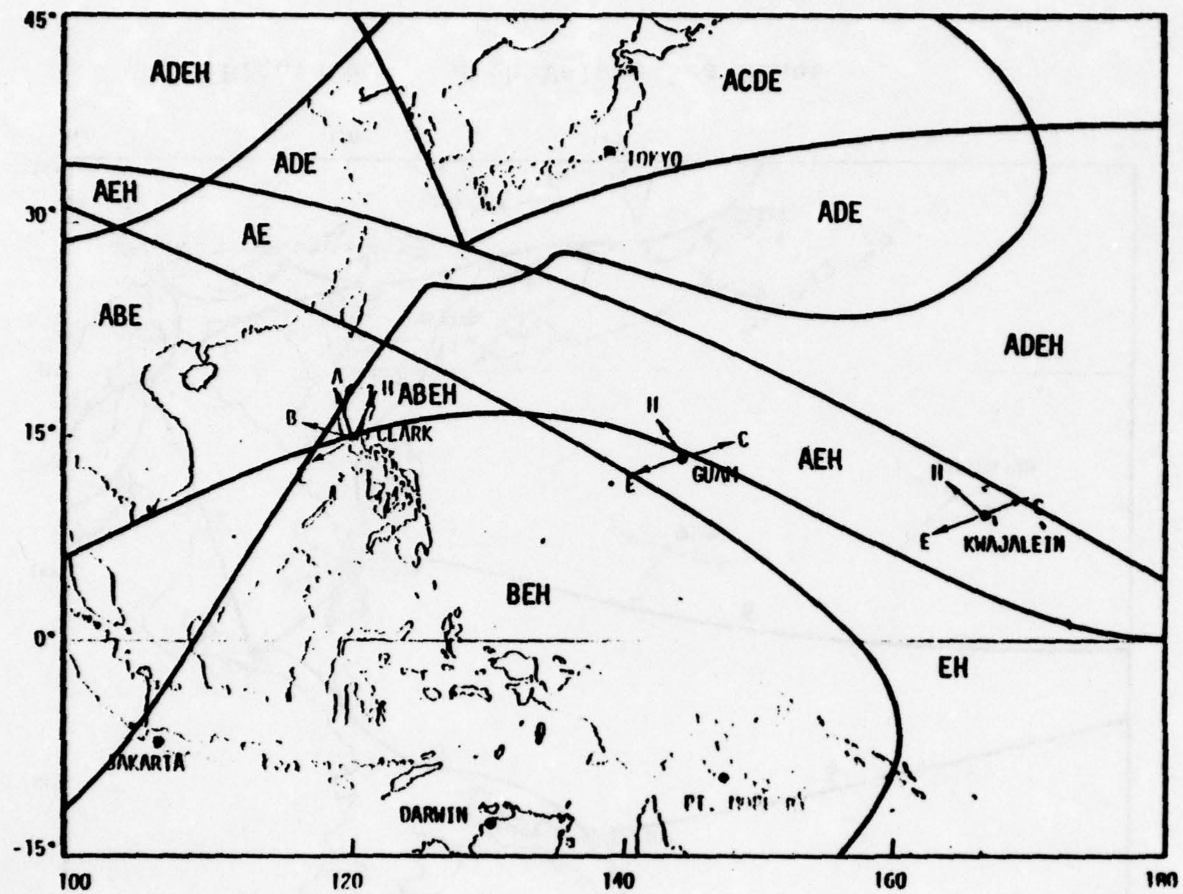


Figure 6.3 Modified Predicted Omega Signal Usability Contours, Day and Night

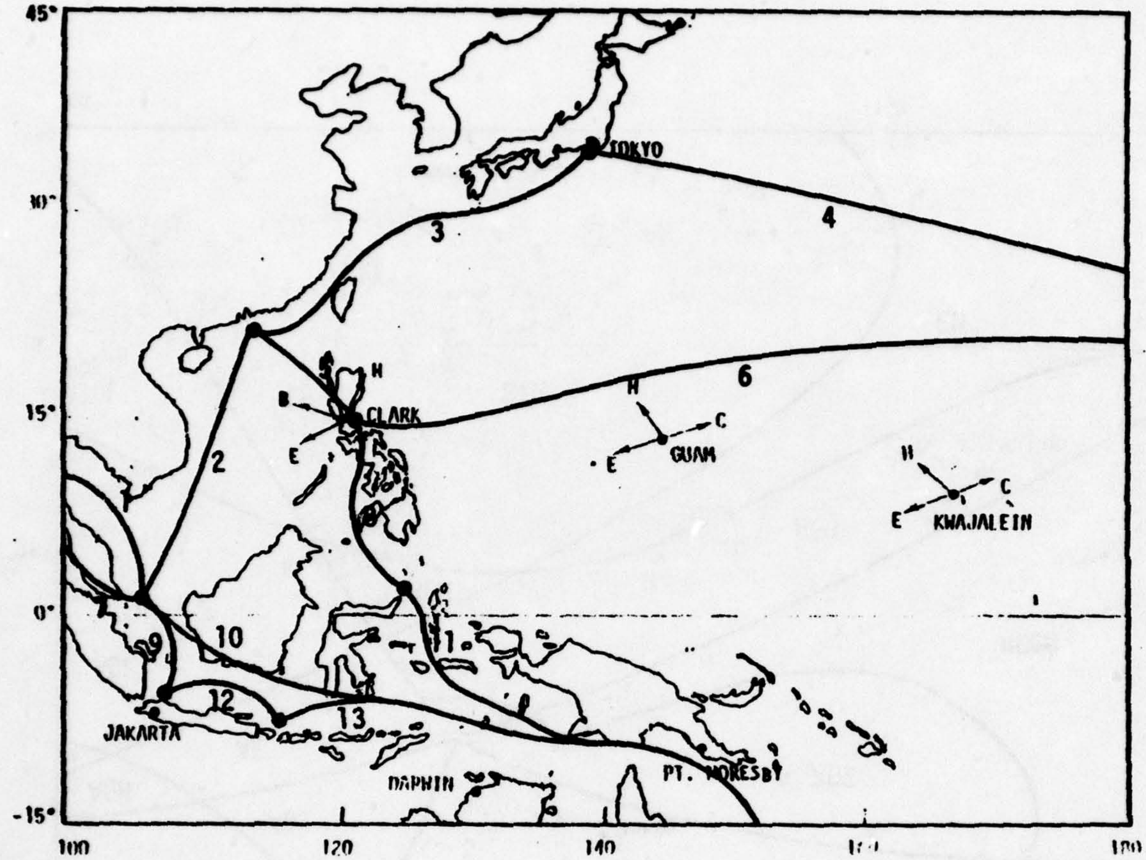


Figure 6.4. High Volume Sea Lanes

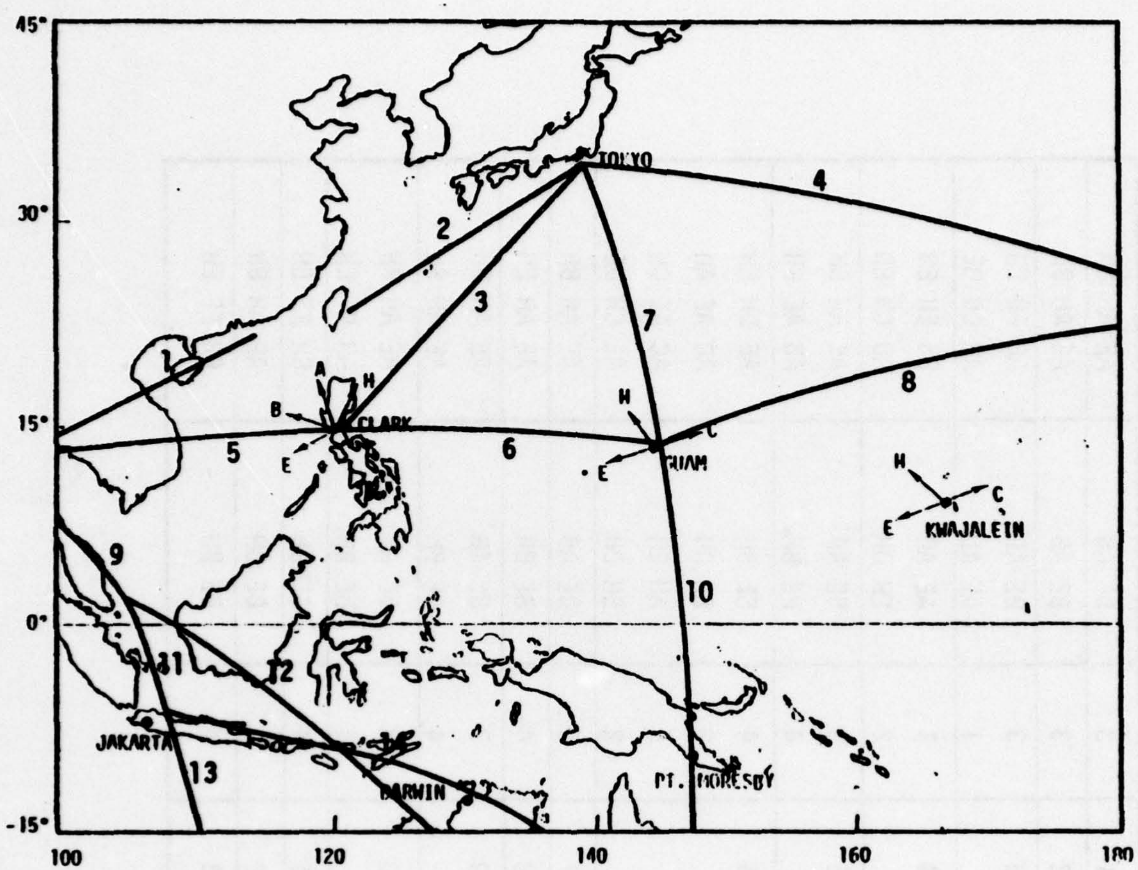


Figure 6.5. High Volume Air Routes

Table 6.2
LOPs for High Volume Sea Lanes

LANE	AREA	PRIMARY LOPs	ALTERNATE LOPs
1	3	BE AB	AE AH BH
2	3	BE AB	AE AH BH
3	3	BE AB	AE AD EH
	1	AE AD	AH CD DE
4	1	AE AD	DH EH ED
	2	EH DH	AD CH ED
5	3	BE AB	AE AH BH
	4	BE BH	AB AE EH
6	4	BE BH	AE DH EH
	2	EH DH	AC AE AH
	5	AH EH	AC AE DH
	2	EH DH	AE CH DE
7	3	BE AB	AE AH BH
8	4	BE BH	AE AH EH
9	3	BE AB	AE AH BH
	4	BE BH	AE AH EH
10	3	BE AB	AE AH BH
	4	BE BH	AH EF EH
11	4	BE BH	CH EF EH
12	4	BE BH	AE AH BH
13	4	BE BH	CH EF EH

Table 6.3

LOPs for High Volume Air Routes

LANE	AREA	PRIMARY LOPs	ALTERNATE LOPs
1	3	BE AB	AE AH BH
2	1	AE AD	AH CD DE
3	4	BE BH	AE AD AH
	1	AE AD	AH CD DE
4	1	AE AD	DH EH ED
	2	EH DH	AD CH ED
5	3	BE AB	AE AH BH
	4	BE BH	AB AE EH
6	4	BE BH	AE DH EH
	2	EH DH	AC AE AH
7	2	EH DH	AC AE AH
	5	AH EH	AC AE DH
	2	EH DH	AD AE CH
	1	AE AD	AC CE DE
8	2	EH DH	AC AE AH
	5	AH EH	AC AE DH
	2	EH DH	AE CH DE
9	3	BE BH	AE AH BH
10	2	EH DH	AE BE BH
	4	BE BH	AE AH BH
11	3	BE AB	AE AH BH
	4	BE BH	AH EF EH
12	3	BE BH	AE AH BH
	4	BE AB	AH EF EH
13	3	BE BH	AE AH BH
	4	BE AB	AH EF EH
14	4	BE AH	AE AH BH

The use of 13.6 kHz gives more reliable operation than 10.2 kHz. Analysis of ONSOD monitor data shows that 13.6 kHz is more reliable and has smaller errors than the 10.2 kHz signals. Operational use by a maritime ship, during transit from Okinawa to Jakarta, achieved 58 position fixes out of 59 tries at 13.6 kHz compared to 48 out of 59 tries for 10.2 kHz. Multiple frequencies should be used whenever possible to improve position fixing reliability.

6.4 LANING OPERATIONS

One of the original motivations for incorporating the additional frequencies into the Omega system design was to permit the user to employ difference frequency techniques to generate difference frequency lanes much larger than the intrinsic 8 nmi lane width afforded by the basic 10.2 kHz frequency. Utilizing just the two frequencies 10.2 kHz and 13.6 kHz theoretically increases the unambigious lane width to 24 nmi. Similarly, use of all three present frequencies increases it to 72 nmi, and incorporation of the fourth frequency will further increase the unambiguous lane width to 288 nmi.

Data from ONSOD monitoring sites was collected simultaneously on 10.2 kHz and 13.6 kHz at four sites. An attempt to confirm laning operation was made by completing the 3.4 kHz phase difference and finding the error between the 3.4 kHz and the 10.2 kHz phase. Figures 6.6 and 6.7 illustrate this process for the hourly means at Clark on July 1976 for LOP EH and at Tsushima on July 1976 for LOP CD. If the difference between the 3.4 and the 10.2 kHz phase is more than 50 CEC, the laning process will select the incorrect 10.2 kHz lane.

For this data a laning error will occur for 23% of the measurements at Clark and 14% of the measurements at Tsushima. Since the majority of the laning errors occur with large mean errors,

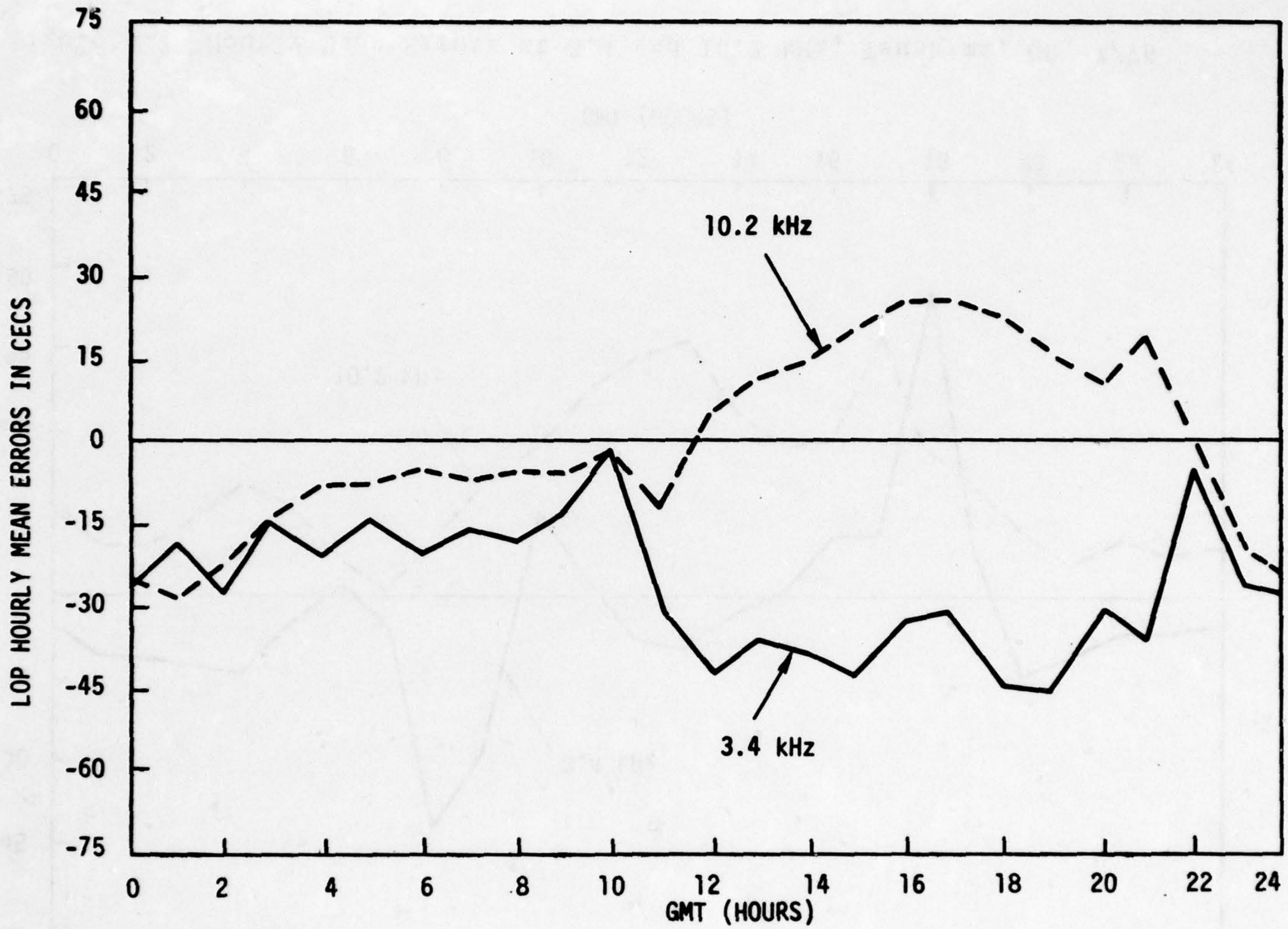


Figure 6.6 Hourly Mean Errors at 3.4 and 10.2 kHz, Clark, EH, 7/76

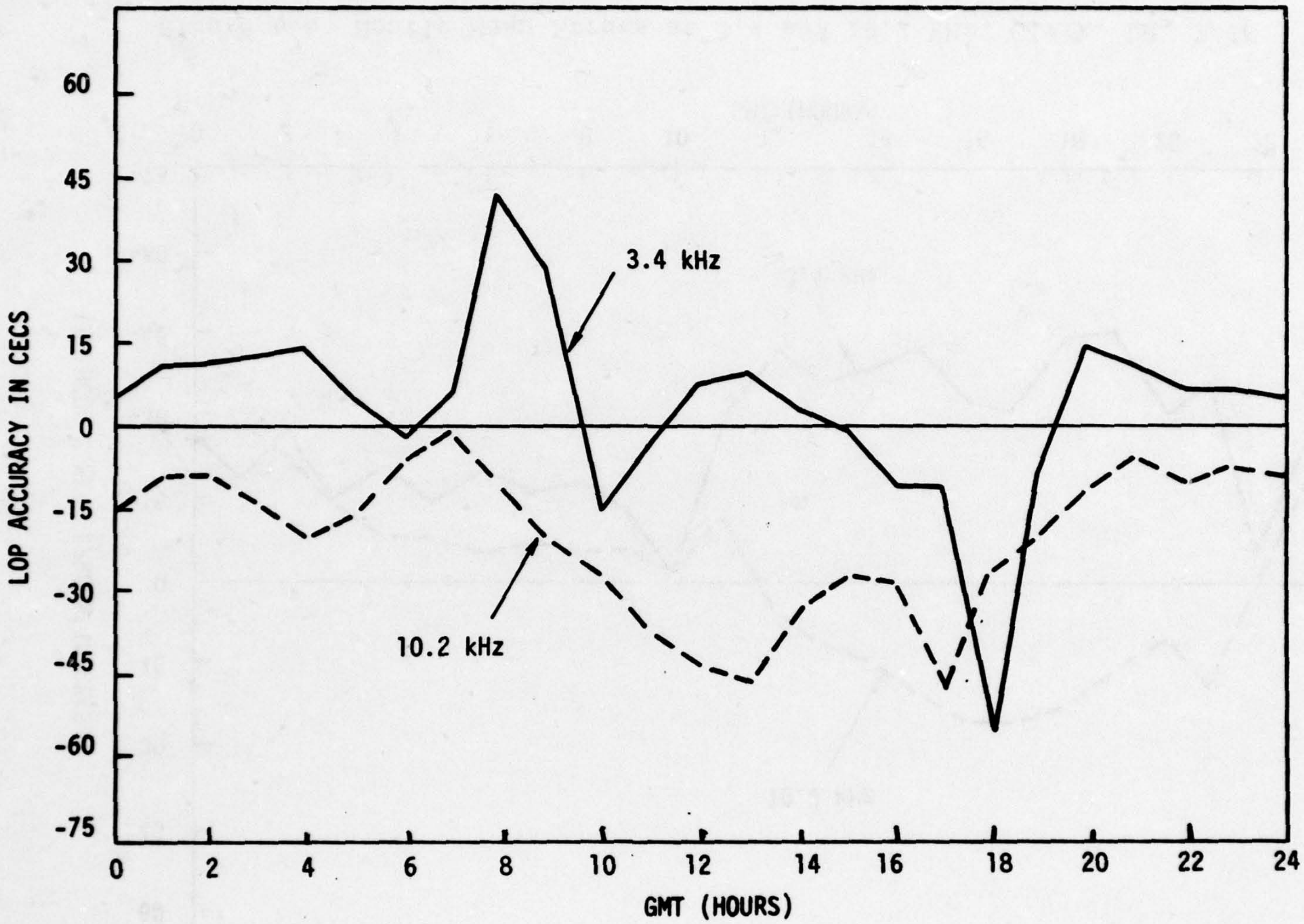


Figure 6.7 Hourly Mean Errors at 3.4 and 10.2 kHz, Tsushima, CD, 7/76

improvements in the PPCs will give substantially better laning performance. The data was reprocessed, first removing the hourly mean errors, and the laning error percentages were reduced to 3.9% and 2.8%.

6.5 ADDITIONAL BENEFITS OF MULTIFREQUENCY OPERATION

Additional benefits may be derived by simultaneously using all of the Omega signals.

When all of the frequencies are present, the signals can be processed to provide an increase in the effective signal-to-noise ratio. On the average, an increased signal-to-noise compared to single-frequency use can be provided as follows:

2 frequencies	3 db	relative to one frequency
3 frequencies	4.7 db	
4 frequencies	6 db	
4 frequencies & unique frequency	9 db	

Using all frequencies, Omega signals from each station are received in all eight time slots of the 10 second Omega signal format period. This provides a maximum possible position update eight times in the 10 seconds or an average of 1.125 seconds. Thus, a higher effective update rate can be achieved by processing all frequencies.

VII. CONCLUSIONS AND RECOMMENDATIONS

7.1 COVERAGE ASSESSMENT

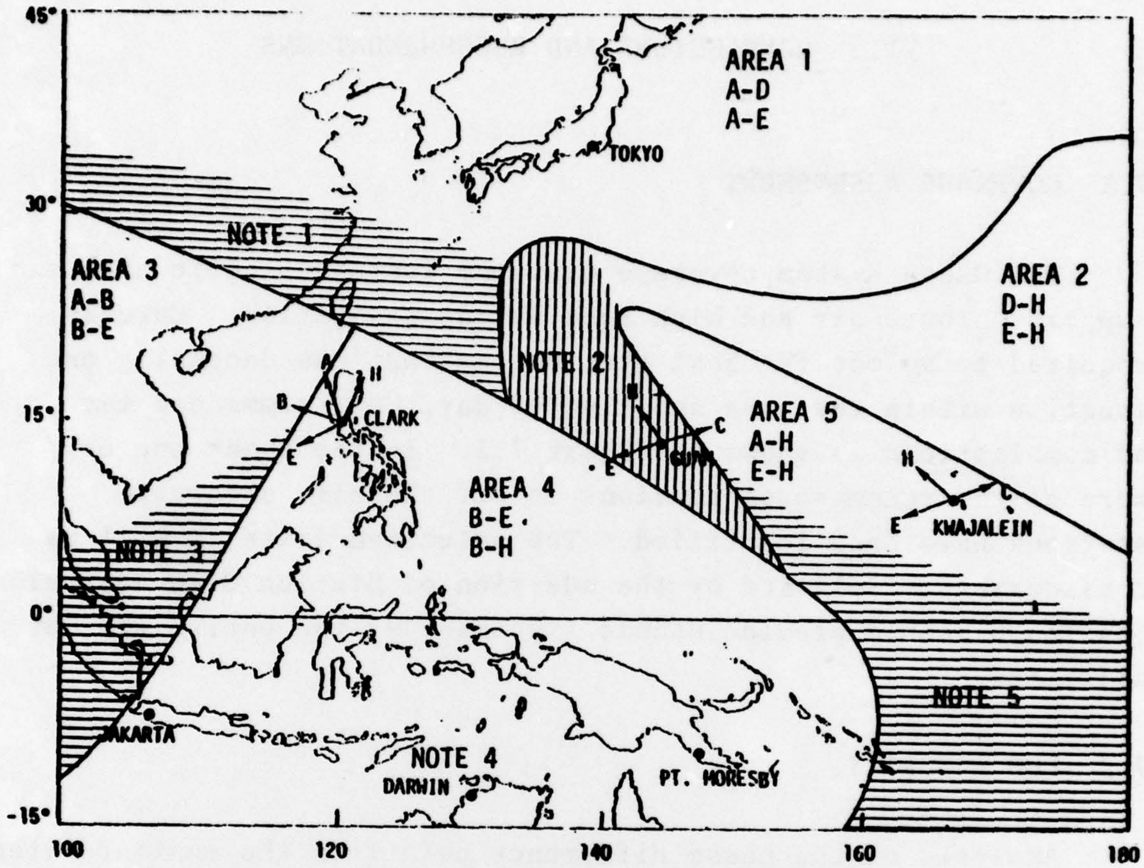
The Omega system coverage over the Western Pacific area can support enroute air and high seas marine navigation. Care is required to select the best station combinations depending on location within the area and time of day. A recommended set of combinations is shown in Figure 7.1. In the event one or more of the recommended stations is off the air, alternate stations have been identified. The selection criteria will be considerably simplified by the addition of Station G in Australia. Station G should provide usable signals over the entire area at all times.

7.2 LOP ACCURACY

Analysis of the phase difference data from the monitor sites indicate LOP accuracies with hourly mean averages of about 15 CEC. Standard deviations about the means of less than 10 CEC are generally observed. The hourly mean errors can be substantially reduced by improving PPCs, resulting in a significant improvement in position accuracy and laning reliability. When the Australia station, G, becomes operational, LOP errors (both means and standard deviations) will be improved since strong stable signals from G can be paired with other signals in the area to provide more reliable LOPs.

7.3 POSITION FIX ACCURACY

Omega position fix accuracies were determined by combining available LOP pairs. The 95% circular error ranged from 4.4 nmi to 7.1 nmi for automatic receivers and 5.4 nmi to 8.6 nmi for manual receivers using the present PPCs. PPC improvement can



Note 1: H can be used as an alternate for D during local daytime in shaded area.

Note 2: C can be used as an alternate for D during local daytime in shaded area.

Note 3: H can be used as an alternate for A during local daytime in shaded area.

Note 4: Alternate stations are not required in Area 4 when the recommended stations B, E, and H are available.

Note 5: C can be used as an alternate for A during local daytime.

Figure 7.1 Recommended LOPs for Western Pacific Area Coverage Based on Use of 10.2 kHz Only and Without Station G (Australia) Coverage

significantly reduce these errors since the hourly mean errors are generally larger than the variations about them. Position fix accuracies will be further enhanced by the advent of the Australia station, G, since the azimuth of the arriving signals from G in the Western Pacific provide improved geometric LOP combinations when combined with signals now available.

7.4 LORAN-A REPLACEMENT

In the areas that were serviced by Loran-A 1H1, 1H2, 2L1, 2L2, 2L3, and 2H6 chains which were discontinued on 31 December 1977, current Omega coverage from at least three stations is available. Over the Mariana Island region, redundant coverage is marginal during times when either Station E or H is off the air. Station G, Australia, will provide the needed redundancy over this region.

7.5 CHARTED LOPs

Recommended LOP pairs should be noted on Omega charts in those regions where they provide the best service. Alternate LOPs should also be noted, with an indication of the performance to be expected.

7.6 SIGNAL-TO-NOISE RATIOS

The Omega data analyzed generally supports the coverage predictions. In those cases where minor differences were found, the predictions based on the Effective Single Mode Model are usually more conservative than the data indicate. The significant differences that exist, observed during NOSC temporary site measurements are: signal strength from Station B is 8 to 18 db higher than predicted at Clark, Orote Point, Port Moresby and Darwin, and signal strength from Station C is 4 to 10 db lower than predicted at Port Moresby and Darwin.

7.7 MODAL INTERFERENCE

Modal interference is predicted from Station H, Japan, during nightime within the sector between the 190^o and 225^o bearing angles from the station. Flight tests conducted on bearings of 205^o and 215^o from the station validated the predictions and showed the deepest nulls at approximately 3 and 4 Mm (1620 and 2160 nmi) from the station. Modal interference is predicted from Station C, Hawaii, during nighttime within the sector between the 190^o and 295^o bearing angles from the station. Amplitude data from nighttime test flights between Hawaii and Wake Island on approximately a 270^o bearing from Hawaii, confirmed the existance of modal interference. However, the test data amplitude signatures from the two flights did not correlate well with each other or with the predictions indicating significant night-to-night variations in the modal structure. Navigation based on a single frequency exhibiting severe modal interference is susceptible to lane slippage. The modal nulls at different frequencies are spatially displaced which suggests the use of two or more frequencies as a means to reduce the incidence of modally induced lane slippage.

7.8 MULTIFREQUENCY OPERATION

Use of multiple frequencies gives a significant increase in the availability of position fixing over the use of 10.2 kHz only. The 13.6 kHz signal provides a better received S/N than does 10.2 kHz. Based on the data analyzed, the 3.4 kHz difference frequency does not appear to provide sufficient accuracy for reliable laning with the present PPCs. A realizable improvement in the PPCs should provide adequate laning performance.

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